THE CHEMISTRY OF
CATTLE FEEDING
AND DAIRYING

J. ALAN MURRAY

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WITH ILLUSTRATIONS AND FOLDING CHART

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PREFACE

In the present volume the aim is to develop and explain those fundamental principles which are the basis of all effective control in farming operations rather than to prescribe rules for particular cases. The more important conclusions are, however, brought to the test of comparison with rations actually used by farmers. Numerous examples of the latter are described and criticised in the light of the principles from the dual point of view of efficiency and pecuniary economy.

It is assumed that the reader is familiar with the rudiments of inorganic and organic chemistry, but not necessarily with the more advanced work on proteins, carbohydrates, etc. This is given in condensed form in Part I. together with some constitutional formulæ and other matter occasionally required for reference. It is possible, therefore, to avoid digression in the remaining sections which deal with the requirements of the animals, the feeding stuffs and the chemistry of dairying, respectively. The last-mentioned subject cannot well be separated either from the preliminary matter above referred to or from the question of milk production which, of course, is dealt with in Part II.

The data are derived partly from the German and partly from American experiments, and the interpretation of them is based largely upon the Rothamsted investigations. The feeding standards of Wolff and Kellner's system of starch equivalents are examined; but an attempt is made to break away, more or less completely, from both, and from the tyranny of the rule of three in which they are involved. It is now generally acknowledged that the requirements of animals are not proportional to the mass. The idea is to dissociate the several elements—the requirements for maintenance, fattening, etc.—comprised in the various feeding standards, and to express each by a simple formula. Finality is not claimed. On the contrary it may be hoped that the obvious defects of the formulæ, which are also inherent, though not so apparent in the feeding standards, will be made the subject of special research. It may be claimed, however, that the formulæ are of more general application than the feeding standards, and that they yield a closer approximation to the truth regarding the requirements of the animals in any given case.

The work is essentially quantitative in character, and in order to master the principles it is necessary to grasp the reasons for each step in the calculations. The interest of novelty attaches to the graphic solutions of problems in compounding rations described in Chapter XIV., and they are, perhaps, not without educational value. One of them at least has the merit of simplicity, and, in conjunction with the natural classification of the feeding stuffs according to their position on the chart, may prove to be of practical utility.

The book is intended mainly for the use of students pursuing college courses in agriculture, but it is hoped that it may be useful also to practical farmers who have some previous knowledge of chemistry. For this reason English standards of mass and measurement are adhered to throughout; but in order to simplify the calculations and facilitate comparison with the metric system only decimal multiples of the fundamental units are employed. The adoption of the "kilo-pound unit," *i.e.* the amount of heat required to raise the temperature of 1000 lbs. of water 1° C., is no doubt open to criticism No justification, save that of convenience, is offered either for the thing or for the name.

The author gratefully acknowledges his obligation to all the great army of predecessors and fellow workers as well as to the authorities more particularly mentioned in the text. Thanks are due also to Mr. J. W. Dodgson and others for criticism and suggestions and for assistance in revising proofs.

READING,
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THE CHEMISTRY OF CATTLE FEEDING AND DAIRYING

CHAPTER I

INTRODUCTORY

THE mass of an animal increases manyfold in the interval from the time it is weaned till it reaches maturity. The whole of the material comprised in this increase is derived from the food and water consumed. There is no other source.

Animals may be classed as carnivorous and herbivorous according as they exhibit a preference for, and are adapted to subsist on, a diet of flesh or of vegetable matter. Farm animals—horses, cattle, sheep, pigs, etc.—all belong to the latter class. But the food even of the carnivora is of course also derived ultimately from vegetable matter.

It is not surprising, therefore, that plants and animals—notwithstanding the difference in their external forms and mode of existence—exhibit a general similarity in chemical composition. In view of the fact that animals live on plants we should expect to find that they are composed of the same chemical elements. It is obvious, at least, that only those which are present in plants and in water can enter into the composition of animals. As a matter of fact, the same chemical elements are found in both. They are as follows :—

Carbon
Oxygen
Nitrogen
Hydrogen
Sulphur
Phosphorus
Sodium
Potassium
Magnesium
Calcium
Iron
Chlorine
Fluorine
Silicon

These substances are not present in the same relative proportions in the two types. Animals, for instance, usually contain larger proportions of nitrogen and phosphorus than plants. Some of the elements mentioned above do not form part of the tissues. They are found only, or chiefly, in the juices or fluids where they perform various functions of greater or less importance in the economy of the organism.

Of those which actually enter into the composition of the tissues it may be said, in general, that they are combined in a similar manner. In other words, plants and animals are composed, not only of the same chemical elements, but also, to a large extent, of the same kinds of chemical compounds.

This fact is of fundamental importance. It could not be deduced from any *à priori* considerations; and it is the more striking in view of the numerous and complex chemical changes which the food of animals undergoes in the processes of digestion and after absorption into the blood.

The more important chemical compounds found in plants and animals may be classified as (*a*) nitrogenous substances, (*b*) fats or oils, (*c*) carbohydrates, (*d*) mineral salts, and (*e*) water. It must be clearly understood that, with the exception of water, these are not the names of particular substances but of groups or classes of compounds. Each of the groups includes many different compounds which must be further classified by sub-division according to their properties.

Certain compounds occur only in plants, others only in animals; and some are peculiar to particular kinds or varieties of plant or animal. The fats or oils found in plants are not identical with those of animal origin. Palm oil, for instance, is not the same as lard. The fat of one kind of plant or one kind of animal is not exactly the same as that of any other plant or animal. Linseed oil, olive oil, and castor oil are all different; so also are butter fat, beef fat, and mutton fat. They exhibit well marked differences in their properties and are easily distinguished one from the other; but they are all fats. They are similar in composition, possess certain properties in common, and all belong to the same chemical class.

In like manner, the albuminoids or proteins—which are included in the nitrogenous substances—of plants are not identical with those of animals. The proteins of one kind of plant or animal are not identical with the proteins of another plant or animal, but they are similar in composition, exhibit certain common properties, and are, therefore, all referred to the same chemical class or group.

Animals require food not only to increase their mass but also to maintain it. If an animal which has reached maturity be deprived of food, a reverse process takes place, the mass, which is measured by weight, diminishes, and in a short time the animal dies of starvation. This reverse process is due to the respiration of the animal which causes the tissues to become oxidised. It has been compared to the burning of a fire. It is actually and in truth a process of slow combustion. The substance of the body is gradually consumed and certain quantities of food must be supplied from time to time in order to repair the waste. If the quantity of food is not sufficient to counterbalance the loss due to oxidation, the mass, *i.e.* the weight, of the animal is diminished. On the other hand, if more material is absorbed than is lost by oxidation in the same time, the excess may be stored up in the body and increase of weight results.

When a fire burns, heat is produced. That heat is produced by the slow combustion which goes on in animal bodies is evident from the fact that the bodies are warm. Much of this heat is lost by radiation from the skin and it is essential to maintain the body at the proper temperature. The food serves as fuel for this purpose.

All work involves the expenditure of energy. When an animal does work, the energy is derived from the oxidation of the food. The circulation of the blood is a form of work which may be compared to pumping water from a well. The operation of the processes of digestion is another form of work. There is, therefore, a continual demand for energy for the internal work of the animal. But if the animal is called upon to do additional (external) work, such as running or hauling, an additional supply of energy is required. Animals therefore require more food when they do external work than when at rest.

Matter can undergo various physical and chemical changes, but the total quantity remains unchanged. In other words, something cannot be produced from nothing. This fundamental law of nature is applicable to the changes which take place in living organisms as well as to those in inanimate substances. Animals cannot produce milk, or eggs, or fat, or wool, or anything else, from nothing. All that they can do is to transform the constituents of the food into the constituents of these things. Only certain kinds of materials are capable of undergoing such changes. Animals producing milk, or fat, or any other substance, require more food than similar animals which are not producing these things; and the additional food must be of suitable character.

The food of animals consists of plants, *i.e.* of the chemical compounds of which plants are made up. It is these compounds that are used by the animal to repair the waste due to oxidation; they serve as fuel to maintain the temperature of the body and to provide the energy required for the performance of work. It is by the transformation of these chemical compounds into others that the mass of the animal is increased, and that milk, wool, eggs, etc., are produced.

Any substance that will burn will do to make a fire, but some are more suitable than others. Coal, for instance, gives a hotter and more lasting fire than twigs or paper; but it may be remarked in passing that if equal masses were compared, the difference would not be so great as is sometimes supposed. In like manner, almost any oxidisable substance that the animal can absorb will serve for those purposes in which the food serves as fuel, *e.g.* to maintain temperature, to enable the animal to do work. But the various compounds of which the food is composed have very different values in this respect. Some of them give out much more heat or energy than others. A pound of fat, for example, gives out between two and three times as much heat as an equal quantity of protein or carbohydrate.

Any substance will not serve to repair the waste due to oxidation, to increase the mass of the animal when growing or fattening, or for the production of milk, wool, etc. The tissues, milk, wool, etc., are composed of certain chemical compounds. Some of the compounds of the food can be transformed into these; others cannot. Non-nitrogenous compounds, for example, cannot be transformed into nitrogenous compounds. The food of animals must be not only sufficient in quantity, but it must also be of the right kind. In short, it must contain certain minimum quantities of the particular compounds required for each specific purpose.

This has long been recognised by farmers and other practical men. Store cattle and horses doing no work are fed on hay, straw, roots, etc.; but when they are to be fattened, or do work, they are given oil cake, oats, and other rich and expensive foods. Practical men are faced with several important problems in this connection, and if they do not exercise a right judgment in regard to them their operations will result in financial loss or, at least, in diminished profits. They know by experience which kinds of food are more or less suitable for particular purposes and approximately what quantities of each are requisite and advisable in particular circumstances. Indeed, it is from this point—the accumulated experience of many generations of farmers in this and other countries—that all scientific investigation of the problems must begin.

Uncontrolled experience, however, does not tell us why one food is more suitable than another or how new foods, which are introduced from time to time, should be used. It does not show which of the suitable foods will be the most economical, financially, for any specific purpose, or what quantities of any one kind of food should be used to replace a given quantity of another. Briefly, practical experience does not, by itself, enable the farmer to exercise adequate control over his operations, to deal successfully with abnormal conditions which arise from time to time, or to understand and utilise to the best advantage the advice of experts in regard to such matters. To do this he must have exact knowledge of the requirements of the animals and of the composition and properties as well as of the prices of the various kinds of feeding stuffs.

Such knowledge implies a clear understanding of the relationships of the several classes of compounds which enter into the composition of plants and animals, of the more important processes of animal nutrition and of the nature of the chemical changes involved. These subjects are discussed in the first and second parts respectively of this book. The third section is devoted to an account of the origin, composition and properties of the various kinds of food stuffs and shows how they can be suitably combined, qualitatively and quantitatively, for various purposes.

The fourth section of the work is devoted to the chemistry of dairying. This subject is closely connected with those of the preceding sections and cannot, advantageously, be treated apart from them.

PART I.—CONSTITUENTS OF PLANTS AND ANIMALS

CHAPTER II

THE MINERAL SALTS

Chemical Composition of Ashes.—When animal or vegetable matter in its natural state is burned, a large part of it disappears in the form of gases, but some solids always remain behind as ashes. The quantity of ash ingredients varies widely in different kinds of organic matter. In the bones of animals it may amount to between 40 and 50 per cent. of the original substance. Chaff, husks, and withered leaves contain from 10 to 20 per cent. or more of ash ingredients. On the other hand, the muscular and fatty tissues of animals, the inner portions of seeds, potato tubers, fleshy roots, etc., contain only a very small proportion—rarely more than 2 or 3 per cent. of the dry matter, and in some cases less than 1 per cent.

The ash will usually be found to contain some of all elements originally present in the organic matter—*i.e.* those previously mentioned (p. 2)—except hydrogen and nitrogen, which are completely volatilised on incineration. The elements are not, of course, present in the ash in the free state, but in combination as oxides, chlorides, and fluorides. The acidic oxides, viz. P_2O_5, SO_3, and CO_2, are further combined with the basic oxides K_2O, MgO, and CaO. The silica and oxide of iron are probably, for the most part, uncombined. It may be said that, in general, the ash consists of the—

$$\left.\begin{array}{l}\text{Chlorides}\\ \text{Fluorides}\\ \text{Oxides}\\ \text{Phosphates}\\ \text{Sulphates}\\ \text{Carbonates}\end{array}\right\}\text{ of }\left\{\begin{array}{l}\text{Sodium}\\ \text{Potassium}\\ \text{Magnesium}\\ \text{Calcium}\\ \text{Iron}\\ \text{Silicon}\end{array}\right.$$

The ash is therefore said to consist of "mineral salts," and these, in turn, are usually quoted as one of the constituent groups of compounds in the proximate composition of plants and animals.

The term "mineral salts," however, is a misnomer, and has often proved misleading. The ingredients of the ash are not "mineral." They are just as much organic products as the fats or proteins; and there is good reason to believe that some of them, *e.g.* phosphorus, sulphur, etc., exist in the plants and animals, not in the form of salts at all, but, to some extent at least, as constituents of the compounds mentioned. At the same time, it must be kept in view that certain salts, *e.g.* common salt, are present in that form in the sap of plants and in the blood, urine, and other fluids of animals.

It is more than probable that the carbonates found in the ashes do not exist in that form in the living plants and animals, but are formed from other compounds in the process of combustion. For this reason, many authors regard the presence of carbonates in the ash as merely accidental, and they deduct the amount of carbon dioxide found from the total crude ash and call the residue "pure ash."

The same argument might be applied to the sulphates. It is tolerably certain that much, if not all, of the sulphates found in the ashes of natural organic substances are formed during the process of combustion by oxidation of the sulphur which, in the original organic matter, formed part of the proteins or other compounds. Fleischman[1] actually does adopt this course in regard to the ash of milk. He deducts the whole of the SO_3 because sulphates are not present in the milk. He also deducts a part of the P_2O_5 corresponding

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[1] "The Book of the Dairy," English translation, p. 27.

to the amount of phosphorus in the casein "in order to find the quantity of phosphoric acid which is present in the milk as such."

It is doubtful, however, whether the argument can be properly extended to the P_2O_5 in this way. There is good reason to believe that the phosphorus in casein is already fully oxidised, *i.e.* that it is present as P_2O_5; and if that be so, one is prompted to ask, why not deduct the CaO which also occurs as a constituent of the casein in the original milk?

There can be no question as to the condition—as regards oxidation—of the sodium and potassium compounds in natural organic matter. These elements occur in the soil chiefly as oxysalts and chlorides, and, as such, are taken up by plants. These compounds may undergo various changes in plants and animals, but they are probably not reduced. The same argument applies also, with more or less force, to the calcium and magnesium compounds.

Functions of the Ash Ingredients.—It is very difficult to determine precisely what functions some of the ingredients of the ash perform in the living organism. In other cases it is more or less readily apparent.

The presence of sodium chloride in plants appears to be purely accidental. The great majority of plants grow as well, and some of them better, in the total absence of this substance. Cattle and sheep, and most other animals, exhibit a strong desire for common salt. When opportunity offers, they will lick it as a child sucks sugar. Salt is frequently mixed with their food as a condiment; it improves their appetites, aids digestion, and appears to be beneficial to their health, but in what way is not known with certainty. It has been argued that a certain amount of common salt is necessary as a source of the hydrochloric acid which is found in the stomach and which promotes the process of peptic digestion. It is probable, however, that the chlorides naturally present in the food of herbivora are sufficient to provide all the hydrochloric acid required.

Potassium compounds are essential for the growth of plants. They appear to be in some way connected with the formation of starch and are usually found in largest proportion in those plants and parts of plants which contain considerable quantities of that ingredient. The laws of diffusion have been invoked to account for the accumulation of potassium compounds in plants; but the explanation leaves something to be desired, unless it be assumed that the potash is withdrawn from solution, *i.e.* that it is converted into insoluble compounds such as potassium hydrogen tartrate. In the ash of plants the potash occurs chiefly as the carbonate.

Potassium compounds appear to be of minor importance in the economy of animals. They occur in the blood of all herbivora as a necessary consequence of their presence in the food. The perspiration which exudes from the skin contains a small amount of potash, and the suint[1] of sheep's wool contains a more considerable quantity. The suint, which is soluble in water, is removed by washing the fleece, and also, more or less completely, when the animal is exposed to rain.

Potassium compounds, reckoned as K_2O, form nearly one-quarter of the total ash of milk, so that the daily yield (say 3 gallons) of each cow contains about one ounce of that substance. A farmer producing milk therefore will find it profitable to use potash manures unless his soil is naturally well stocked with that ingredient. Practically the whole of the potash in the food, except what is exported in the milk, is returned to the land in the droppings of the animals.

Phosphates and calcium and magnesium compounds are indispensable for the growth of plants, but their functions are not well understood. The phosphates are generally found chiefly in the same regions as the protein compounds and are probably

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[1] Physiologically, suint also is of the nature of perspiration. It is not a homogeneous substance, but consists mainly of the potassium salts of several fatty acids, *i.e.* soaps, amongst which oleic, stearic, and cerotic acids predominate. Acetic, propionic, butyric and caproic acids are also present together with phenol, benzoic acid, uric acid and several amides, *e.g.* glycocine, leucine, and tyrosine in smaller quantities. As a whole, it contains about 4 per cent. of potash, and is soluble in water; the wool fat is insoluble in water but soluble in ether, etc.

associated with them in some way. Some protein compounds contain phosphorus as a constituent element (pp. 74, 79). Apart from this, the formation of proteins in plants appears to depend upon the presence of phosphates. In the plants calcium salts react and form compounds with injurious or superfluous products, *e.g.* oxalic acid, chlorine, etc. These find their way, by processes of diffusion, towards the exterior parts of the plants, where they are either deposited as insoluble salts or are washed off by rain. The calcium and magnesium compounds are probably also connected with the vital functions of the organism in other ways.

In the case of animals, the relations between the phosphates and the proteins are probably not less important. But, in vertebrate animals, the phosphoric acid and lime are chiefly concentrated in the bones in the form of tricalcic phosphate, $Ca_3(PO_4)_2$. It is this substance which gives rigidity to the bones. The proportion of phosphates in bones varies with the kind and age of the animal, but usually, in full-grown mammals, nearly half the mass of the bones consists of tricalcic phosphate.

The phosphates in the food are, therefore, to a large extent retained by growing and milk-producing animals, and the droppings, which go to form the farmyard manure, contain relatively small amounts of that ingredient. Indeed, it was the perception of this fact which led to the introduction of "artificial" phosphatic manures. These were first used in the form of bones, and the idea was to restore to the land the phosphates which are retained by the animals to build up their skeletons.

The question then arises whether it is necessary or advisable to increase the amount of phosphates and lime by direct addition of such compounds to the food of growing and milk-producing animals. There is very little certain information on this point. A few experiments have been carried out, and though the results appear to indicate that the direct addition of phosphates to the food had a favourable effect upon the growth of the animal, the difference was too small to be of much importance. Such additions cannot be regarded as necessary, and it has never become customary to make them in practice. Under ordinary conditions, the natural food and drinking water contain enough phosphates and lime to satisfy all the requirements of the animal.

Besides phosphate of lime, bones contain a small quantity of magnesium and fluorine. Together, these two substances amount to little more than 1 per cent. of the ash, and it is not known with certainty in what form they are present or what functions they perform. In view of the regularity of their occurrence, their presence cannot well be regarded as purely accidental or superfluous.

Silica is a normal constituent of all plants. The fact is probably a necessary consequence of the presence of soluble silicates in the soil. Of cultivated plants, the grasses and cereals contain the largest amount. Possibly because they have a greater capacity for assimilating such compounds. Silica is found in largest quantity in the stems and leaves and in the husks of grain—always in the exterior portions—and is regarded by botanists as of the nature of an excretum. It is never concentrated in the regions of active growth or stored up with embryonic nourishment. It forms a protective covering for seeds and perhaps increases the rigidity of straws and stems, but, apparently, it is not indispensable for the growth of the plant.

The presence of silica in animals is practically limited to wool, hair, feathers and similar epidermic structures. It occurs only in insignificant quantities and its presence is probably accidental. The silica[1] in the food consumed by animals is excreted unchanged, and it is safe to say that it has no nutritive value.

Oxide of iron occurs only in very small proportions in the ash of plants, but is found in more considerable quantities in animals. It is probably an essential constituent of both. Certain protein compounds of the blood and possibly also of the muscular tissues contain iron as an essential ingredient.

To sum up, it may be said that of the ingredients of the

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[1] N.B.—The term "silica" is not synonymous with sand, though it is often said to be.

ash, some are of vital importance in the economy of both plants and animals. Others, though normally present, are probably not indispensable, but may be of use indirectly. From the point of view of the practical cattle feeder they are all unimportant inasmuch as they are always present in the natural food of the animals. If the food be sufficient in quantity and suitable in other respects, it will certainly contain enough "mineral salts" for all ordinary purposes. It is unnecessary, therefore, to add any ash ingredients, except common salt, to the ordinary rations of the animals.

CHAPTER III

THE CARBOHYDRATES

General Properties.—The carbohydrate group includes a large number of compounds, very different in external appearance and properties; but they resemble each other in chemical composition, and they are so much alike in molecular structure that each one of them can be transformed into other compounds which still exhibit the properties that are common to the whole group. They are composed of the elements carbon, oxygen, and hydrogen, and it is characteristic of these compounds that the hydrogen and oxygen are always present in the same relative proportion as in water, *i.e.* two atoms of the former to one of the latter, hence the name "carbohydrate." The carbohydrates which occur in nature usually contain six, or a multiple of six, atoms of carbon in the molecule, but this is not an essential characteristic of the whole group.

In the natural condition many carbohydrates exhibit a definite organised structure; some are crystalline and others are amorphous. All the crystalline and most of the amorphous compounds are more or less soluble in water. Those which exhibit an organised structure are insoluble. Solutions of carbohydrates, when pure, are colourless, neutral to litmus, and are optically active (see p. 38); or if not, physical isomers which are optically active can be prepared from them.

The carbohydrate group includes so many diverse compounds that very few reactions are common to them all. The following, however, are characteristic.

Ferric chloride produces no coloration.

Concentrated sulphuric acid dehydrates and chars them, causing a brown or black coloration. In the presence of α-naphthol, sulphuric acid gives a red colour which rapidly changes to purple. This is known as the Molisch reaction; it is very delicate, and is the best general test for carbohydrates. It is due to the formation of furfural by the action of the acid on the carbohydrate.

Occurrence and Functions.—Carbohydrates are typically vegetable products. They form the chief structural element of plants, and are stored up in large quantities in seeds, roots, tubers, etc. Usually from 50 to 90 per cent. of the dry matter of plants consists of compounds which belong to the carbohydrate group. All the soluble compounds and some of those which are insoluble in water are readily digestible by animals. The remainder are either wholly or partially indigestible. The digestible carbohydrates may be transformed into other compounds and stored up as tissue in animal bodies. They readily undergo oxidation, and the energy produced may be used to perform work or maintain the temperature of the body. They are, in fact, amongst the most important nutrient substances in the food of farm animals.

Carbohydrates are produced by animals only in insignificant quantities. They occur only in the juices and fluids, *i.e.* they play no structural part, and may be regarded, for the most part, as transformation products.

Classification.—The carbohydrates which occur in nature and are of agricultural importance may be divided into three principal groups as follows:—

A. Sugars, *e.g.* cane sugar, milk sugar, etc.

B. Amyloses, or polysaccharides, *e.g.* starch, cellulose, dextrine, etc.

C. Mucilaginous substances of unknown or indefinite composition.

Sugars.—The sugars are all soluble in water and can be crystallised from saturated solutions. They diffuse through semi-permeable membranes, exert considerable osmotic pressure, and are therefore easily absorbed by animals. They are neutral to litmus and exhibit a characteristic sweet taste. Sugars are strictly non-volatile. When heated in the dry state they are changed into a black, fusible, amorphous, soluble substance of indefinite composition called caramel. At higher temperatures they are completely charred—the whole of the hydrogen and oxygen is given off and only black amorphous carbon remains. Sugar solutions form one of the most readily available sources of carbon for the nourishment of moulds and micro-organisms of various kinds. Under suitable conditions they undergo many different fermentative changes.

Sugars may be conveniently divided into two principal sub-groups as follows:—

(1) Those of the general formula, $C_nH_{2n}O_n$, not hydrolysed by dilute acids.

(2) Those which are split up by dilute acid hydrolysis into compounds which belong to the first sub-group. They are apparently derived from the latter by condensation or combination of two or more molecules with elimination of one or more molecules of water.

Sub-group 1 includes—

Triose (Glycerose), $C_3H_6O_3$.

Tetrose (Erythrose), $C_4H_8O_4$.

Pentoses (Arabinose, Ribose, and Xylose), $C_5H_{10}O_5$.

Hexoses (Glucoses, Mannoses, Guloses, Fructoses, Galactoses, Sorbose, Formose and β-Acrose), $C_6H_{12}O_6$.

Heptoses, $C_7H_{14}O_7$.

Octoses, $C_8H_{16}O_8$.

Nonoses, $C_9H_{18}O_9$.

Also certain substituted products in which atoms of hydrogen are replaced by alcohol radicles, *e.g.* phenylerythrose, $C_6H_5.C_4H_7O_4$.

The substances commonly known as dextrose and lævulose respectively are both hexose sugars. The former is a glucose and the latter a fructose.

Sub-group 2 includes—

Di-pentoses, $C_{10}H_{18}O_9$.

Di-hexoses (Sucrose, Lactose, Maltose, Melitose, etc.), $C_{12}H_{22}O_{11}$.

Tri-hexoses (Raffinose, etc.), $C_{18}H_{32}O_{16}$.

Hex-hexoses (Gentianose, etc.), $C_{36}H_{62}O_{31}$.

Technically, the most important sugars are those which occur in agricultural products, viz. the hexoses, glucose, and fructose, and the bi-hexoses, sucrose, lactose, and maltose, and only those will now be considered.

Hexoses.—Glucose and fructose, when submitted to ultimate analysis, give exactly the same results, viz.—

	Per cent.
Carbon	40·1
Hydrogen	6·6
Oxygen	53·3
	100·0

The empirical formula $C_6H_{12}O_6$ is obtained from these figures and the molecular weight of the compounds. The grouping of the atoms in the molecules is deduced from the reactions and properties of the substances. Thus it appears—

(1) That they are both pentahydric alcohols.

On treatment with CaO, BaO, and PbO, they form saccharates, corresponding to the alcoholates, in which alcoholic hydrogen is replaced by the basic elements. These compounds are decomposed by CO_2.

They also form esters, *i.e.* compounds in which the alcoholic hydroxyl is replaced by acid radicles. The pentacetate $(C_2H_3O_2)_5C_6H_7O$ marks the limit of acetylation, and it is evident, therefore, that the sixth atom of oxygen is differently combined.

Esters of this kind with various organic acids are of common occurrence in plants. They are decomposed on treatment with hydrolytic agents and also by the action of ferments which are always associated with them in the plants. They yield glucose as one of the products and are therefore called glucosides (p. 87).

(2) They are either aldehydes or ketones in respect of the sixth atom of oxygen.

Reducing agents convert them into hexahydric alcohols, sorbite and mannite.

They react with phenylhydrazine, forming hydrazones, compounds in which the aldehydic or ketonic oxygen is replaced by the hydrazine radicle.

$$\underset{\text{(Glucose.)}}{C_6H_{12}O_6} + \underset{\text{(Phenylhydrazine.)}}{H_2N.NHC_6H_5} \rightarrow \underset{\text{(Glucose hydrazone.)}}{C_6H_{12}O_5(N.NHC_6H_5)} + H_2O$$

By a secondary reaction with excess of the reagent they form osazones, compounds which contain two hydrazine radicles.

$$\underset{\text{(Glucose.)}}{C_6H_{12}O_6} + \underset{\text{(Phenylhydrazine.)}}{2H_2N.NHC_6H_5}$$
$$\rightarrow \underset{\text{(Glucosazone.)}}{C_6H_{10}O_4(N.NHC_6H_5)_2} + 2H_2O + H_2$$

As the same osazone

$$CH_2(OH).(CH.OH)_3.C(N_2HC_6H_5).CH(N_2HC_6H_5)$$

is produced from both glucose and fructose, it is evident that the four carbon atoms which are not affected by the reagent are united to the same groups of atoms and that these are arranged in the same way in the two compounds. By the action of strong hydrochloric acid the osazones are converted into osones, and from these hexoses may be again regenerated by reduction with hydrogen.

$$C_6H_{10}O_4(N_2HC_6H_5)_2 + 2H_2O$$
$$\rightarrow 2N_2H_3C_6H_5 + \underset{\text{(Glucosone.)}}{CH_2(OH).(CH.OH)_3.CO.CHO}$$

By this series of reactions, fructose may be obtained from glucose.

(3) Glucose is an aldehyde and fructose a ketone.

By the action of oxidising agents which convert glucose into acids containing six atoms of carbon, the carbon chain of fructose is broken and the products contain less than six atoms of carbon in the molecule.

The difference in the constitution of the two compounds may therefore be indicated as follows :—

$$\underset{\text{(Glucose.)}}{CH_2(OH).(CH.OH)_3.CH(OH).CHO}$$

$$\underset{\text{(Fructose.)}}{CH_2(OH).(CH.OH)_3.CO.CH_2(OH)}$$

According to this view, the two substances are identical as regards four of the carbon atoms and differ only in the arrangement of the atoms attached to the other two. It must be remembered, however, that three physical isomers—the dextro-rotatory, lævo-rotatory, and inactive forms—of each are known; also that other chemical isomers, *e.g.* galactose (which is an aldose like glucose) and sorbose (which is a ketose like fructose), result from the rearrangement of the groups in the molecule as a whole.

Owing to the comparative readiness with which they undergo oxidation, the hexose sugars exhibit the properties of reducing agents. Thus, on warming, they reduce ammonical solutions of silver salts, and alkaline cupric solutions. Many different preparations of this kind, *e.g.* Tollen's, Trommer's, Barfoed's, and Nylander's reagents, are used as tests for the sugars. Fehling's solution is one of the oldest and probably the best for most purposes. It is made by adding strong caustic potash or soda to a solution of cupric sulphate with which some alkaline tartrate has been mixed to prevent precipitation of the cupric hydrate. On warming with hexose sugars, this solution gives a bright red precipitate of cuprous oxide, Cu_2O. The amount of precipitate is proportional to the quantity of sugar present; but when the reaction is used quantitatively, the Fehling's[1] solution must be made and used in the prescribed manner.

The synthetical preparation of hexoses can be effected in several ways. Two of these are of special interest, viz. (1) by condensation of formic aldehyde, and (2) from acrolein bromide.

Formic aldehyde, CH_2O, is known only in solution and in the state of vapour. At ordinary temperatures it changes rapidly into trioxymethylene $(CH_2O)_3$; and this, in the presence of lime, is further changed into a mixture of several hexose sugars from which both glucose and fructose can be isolated.

Acrolein bromide is related to propylene as shown below:—

$CH_2{=}CH{-}CH_3$ (Propylene.)	$CH_2{=}CH{-}CH_2OH$ (Allyl alcohol.)
$CH_2{=}CH{-}CH.O$ (Allyl aldehyde or acrolein.)	$CH_2Br{-}CHBr{-}CH.O$ (Acrolein bromide.)

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[1] Dissolve in separate portions of water 34·65 grains of crystallised cupric sulphate ($CuSO_4 + 5H_2O$), 200 grams Rochelle salt, $KNa\overline{T}$, and 180 grams of caustic soda; then mix the solutions and make up to one litre.

It reacts with barium hydrate, forming barium bromide and a mixture of two sugars called respectively α and β acrose.

$$2C_3H_4OBr_2 + 2Ba(OH)_2 \rightarrow 2BaBr_2 + C_6H_{12}O_6$$

These two substances can be separated by conversion into osazones with phenylhydrazine. The α-acrosazone is identical with the corresponding compound obtained from fructose and can be converted into that substance as previously shown (p. 18).

The dextrorotatory glucose ($[\alpha]_D = 52{\cdot}6$), also called dextrose or grape sugar, is of common occurrence in vegetable products. It enters largely into the composition of grapes, apples, and other fruits, and it forms the chief nutrient of the common root crops, swedes, turnips, and mangels. It occurs also in honey, and is a constituent of urine in certain forms of diabetes.

The commercial product obtained by acid hydrolysis of starch, and sold under the name of glucose or saccharum, contains about 60 per cent. of actual glucose, together with some mucilaginous substances. It is largely employed in brewing and confectionery, and it may also be used in cattle feeding.

Fructose, fruit sugar, or lævulose is also found in honey, in fruits, and other vegetable products, but it is not so common as glucose. Though definitely lævorotatory in its action on polarised light, $[\alpha]_D = -71{\cdot}4°$, it has unfortunately been called *d*-fructose because it was prepared from *d*-glucose and *d*-mannose. When required in quantity, it is usually produced by acid hydrolysis of the inulin obtained from dahlia roots.

Bihexoses.—The elementary composition of the bihexose sugars is represented by the empirical formula $C_{12}H_{22}O_{11}$. They appear to be anhydro-compounds of the hexoses, but they have not yet been synthetically prepared, and the exact nature of the union is still obscure.

The reverse process, *i.e.* splitting up the bihexose sugars into two molecules of hexose, is easily effected by acid hydrolysis (boiling with dilute acids).

$$C_{12}H_{22}O_{11} + H_2O \rightarrow 2C_6H_{12}O_6$$

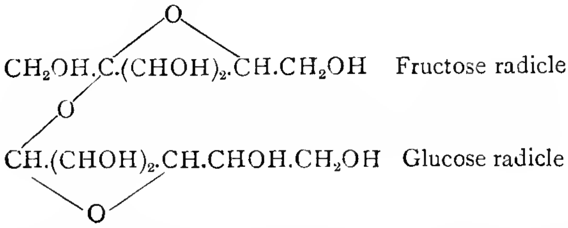
The bihexoses do not undergo direct alcoholic fermentation, but they are easily hydrolysed by a variety of enzymes, and it is probable that this is a condition precedent to all or nearly all the fermentative changes to which they are subject.

Sucrose, saccharose, or saccharobiose is the ordinary household sugar. It is commonly called cane sugar because it was formerly obtained almost exclusively from sugar cane (saccharum officinarum). Large quantities are now obtained from beetroots (Beta maritima) and from certain varieties of maple.

Sugar canes and beetroots, of course, require very different treatment for the extraction of the sugar, but in principle the methods are much alike. Briefly, in both cases, the material is reduced to pulp by machinery, and the juice which contains from 10 to 20 per cent. of sugar is separated by diffusion. Lime is then added to neutralise the acids and precipitate proteins. The solution is filtered through animal charcoal to decolorise it, and concentrated by evaporation in vacuum pans to a thick syrup from which the sugar crystallises on cooling. The product so obtained is called "raw sugar," and the mother liquor containing uncrystallisable sugar is called molasses or treacle.

Pure cane sugar is a very stable compound. It melts without decomposition at 160° C. and resolidifies on cooling. It does not reduce Fehling's solution. It is dextrorotatory in its action on polarised light, $[\alpha]_D = +66{\cdot}5^\circ$. On hydrolysis it is split up into equal molecules of dextrose (*d*-glucose) and lævulose (*d*-fructose), and as the specific rotatory power of the latter exceeds that of the former (p. 20) the optical activity is reversed or "inverted," *i.e.* the mixture is lævorotatory, $[\alpha]_D = -18{\cdot}8^\circ$. This mixture is therefore often called "invert sugar" and the process of hydrolysis is described as "inversion."

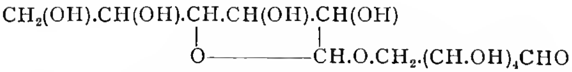
Taking all the facts into consideration Fischer has proposed the formula given below to indicate the constitution of succrose.



Milk sugar, lactose, or lactobiose is a normal constituent of the milk of all mammals, but so far as is known it occurs nowhere else in nature. It may be crystallised from the whey after separation of the fat and nitrogenous compounds. As compared with cane sugar it is not so sweet to taste, is not so soluble in water, and it decomposes more readily on heating. As regards its action on polarised light, it is dextrorotatory, but it exhibits the phenomenon of birotation, *i.e.* when first dissolved in water, $[\alpha]_D = + 83{\cdot}99°$, but after standing for some time it falls to $52{\cdot}53°$. At least three different modifications exist, and the birotation is probably due to the change from one to the other. The common modification obtained by crystallising the sugar from concentrated solutions is hydrated. The other two are anhydrous.

Lactose is split up on acid hydrolysis into dextrose and galactose. As both products are dextrogyrate the rotary effect is not changed in direction but is altered in degree.

Lactose reduces Fehling's solution, and the fact is held to indicate that it contains at least one aldose group unaltered. The union of the two hexoses is probably effected through the other. The molecular constitution may therefore be indicated by the formula



$$\begin{array}{l} CH_2(OH).CH(OH).CH.CH(OH).CH(OH) \\ \qquad\qquad\qquad\quad | \qquad\qquad\quad | \\ \qquad\qquad\qquad\quad O\text{———————}CH.O.CH_2.(CH.OH)_4CHO \end{array}$$

(Lactose.)

Malt sugar, maltose, or maltobiose is produced along with dextrine (p. 32) by the action of diastase (p. 84) on starch when malted grain is "mashed" with warm water in brewing. On hydrolysis with dilute acids it is split up into two molecules of dextrose. This change is not produced by any further action of diastase, and as yeast converts it into alcohol it was thought that maltose was directly fermentable. It is not improbable, however, that yeast contains an enzyme capable of hydrolysing the maltose, and that such a change actually occurs before fermentation. The specific rotatory power $[\alpha]_D = +137°$.

Maltose reduces Fehling's solution. It is considered probable, therefore, that it contains an aldose group, and that the molecular structure is similar to that of lactose.

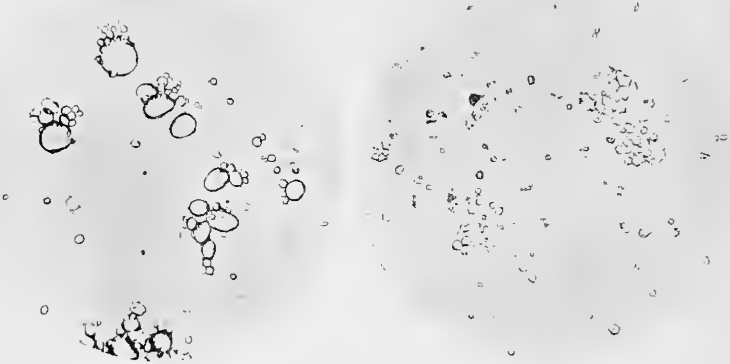
Amyloses or Polysaccharides.—This group includes all carbohydrates of definite composition corresponding to the empirical formula $C_6H_{10}O_5$. They are frequently called polysaccharides because they are all resolved ultimately into hexoses on treatment with hydrolytic agents.

$$C_6H_{10}O_5 + H_2O = C_6H_{12}O_6$$

They cannot, however, be regarded as simple anhydro-aggregates like the bioses and trioses. They are quite unlike the sugars in general characteristics, and one type at least, cellulose, is believed to be a ring compound. Nothing is known of the molecular weights except that it is a multiple of 162 and the formula can only be written $(C_6H_{10}O_5)_n$.

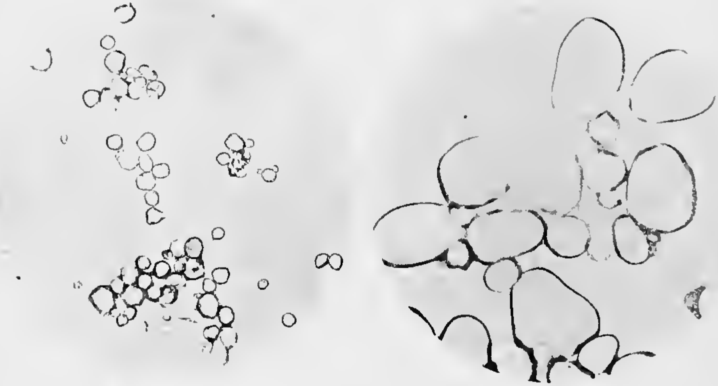
The most important members of the group are: (1) starch and cellulose, which are insoluble and exhibit an organised structure characteristic of the particular plants from which they are derived; (2) dextrine, inulin, and glycogen, which are amorphous and soluble in water.

Starch.—Starch occurs in the leaves and green parts of nearly all plants. It is rapidly formed in bright sunlight when the plant is in a state of active growth, and is one of the first visible products of metabolism. In many cases it is stored up in seeds and in stems, roots, tubers, etc. It is obtained by disintegrating the cellular tissues and washing with water on a fine sieve through the meshes of which the starch escapes The water is then poured off and the starch is dried (p. 282).



Wheat Starch
× 170.

Rice Starch
× 170.



Maize Starch
× 170.

Potato Starch
× 170.

FIG. 1.

When examined under the microscope it is seen to consist of minute granules which vary in size, shape, and appearance. The granules of potato starch are about $\frac{1}{300}$ of an inch in diameter, those of wheat and maize only about $\frac{1}{1000}$ of an inch. The granules of rice starch are still smaller. The first are kidney shaped and exhibit a peculiar concentric lamination. The others are round, oval, or angular and differently marked.

The granules are not entirely homogeneous. They contain a skeleton part which is insoluble in saliva. This forms only about 0·5 per cent. of the whole. It has been called starch cellulose, but has apparently the same composition as the bulk.

When air dry, starch contains from 10 to 12 per cent. of moisture. The larger part of the water evaporates at 100° C., the remainder only on heating to about 110° C. Between 400° C. and 500° C. the starch is converted into dextrine; at higher temperatures it chars, or burns and leaves a small proportion of ash.

Starch reacts with halogens in a manner that is not well understood. Iodine dissolved in potassium iodide solution produces an intense blue coloration. The colour vanishes when the mixture is heated, but reappears on cooling. The reaction is extremely delicate; it is one of the best tests for starch, and has many applications in volumetric analysis.

Water, at ordinary temperatures, has no effect upon starch (p. 23). Hot water causes the granules to swell up and form a colloidal jelly commonly called starch paste. If the paste is very thin, *i.e.* dilute, the starch passes through ordinary filter paper, and the mixture is often called starch solution. The starch, however, settles out on standing, and is probably only suspended in the water. When mixed with water and heated in sealed tubes to 190° C., starch forms a true solution. This soluble form of starch is called amidulin. It reacts with iodine, is insoluble in alcohol, and is, therefore, precipitated as a gelatinous paste on addition of that reagent. It is also precipitated by lime and other basic oxides. On continued heating in sealed tubes at 190° C., or more rapidly at higher temperatures, the amidulin undergoes hydrolysis producing dextrine, maltose, and finally dextrose. This gradual hydrolysis of starch can be effected by simply boiling for a long time (several days) under a reflux condenser. The change takes place much more rapidly in the presence of acids and alkalis, especially the former. Starch is resolved into dextrose on boiling with dilute acids for a few minutes.

By the action of malt diastase at temperatures between 50° and 60° C., starch is converted into dextrine and maltose. It is considered probable that dextrine is formed first, and that maltose results from the subsequent hydrolysis of that compound. At any rate, more dextrine and less maltose is obtained at the higher temperature, and *vice versâ*. The proportion of dextrine to maltose in brewer's worts varies from about one to two to equal parts. By prolonged action of diastase dextrine is converted into dextrose.

Similar changes—conversion of starch into sugars—are also effected by many other enzymes, *e.g.* the ptyalin of saliva and the pancreatic trypsin. Such changes are a condition precedent to the absorption of starch by animals, and are therefore of great physiological importance.

Cellulose.—The term "cellulose" is employed by botanists to describe the material of which the cell wall, as apart from the contents, is composed. It cannot, therefore, be regarded as a single, definite, chemical compound, because the cell walls of living organisms are in a constant, if gradual, state of transition. Considered chemically, *i.e.* apart from their physiological values, these changes take place mainly in the direction of oxidation and dehydration. Cellulose first appears in the plant in a highly hydrated colloidal form. By a series of changes—the obscurity of which is concealed under such names as lignification, suberisation, degradation, etc.—it is converted into various organised structures of which cotton, flax, jute, hemp, wood, cork, etc., may be taken as types. Of these, cotton is the simplest. It has the composition and properties of the typical cell wall, and will therefore be considered in detail. The others, which are also included in the cellulose group, are most conveniently studied by comparison with it.

Cotton is obtained, in the raw state after separation from the seeds, as cotton wool, and in the form of various manufactured products, *e.g.* spun thread, woven cloth, Swedish filter paper, etc.

Under the microscope it presents the appearance of a flattened ribbon with a central longitudinal canal running through it.

FIG. 2.—Cotton cellulose fibres × 250.

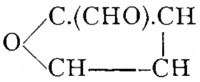
When freed from adventitious matter it is colourless, tasteless, odourless, and quite insoluble in water. The percentage composition—carbon 44·4, hydrogen 6·2, oxygen 49·4—corresponds to the simplest formula, $C_6H_{10}O_5$. It is not at all volatile, but is decomposed—charred or burned—on heating.

Chemically, it is very inert. It offers great resistance to hydrolytic treatment, oxidation, and other modes of attack. Dilute mineral acids, and hot concentrated organic acids, *e.g.* acetic acid, have practically no effect upon it. On heating in sealed tubes with acetic anhydride and sodium acetate, it yields a tetracetate, $(C_2H_3O_2)_4C_6H_6O$. This marks the limit of acetylation, and it indicates the presence of four hydroxyls in the $C_6H_{10}O_5$ group. The formula may therefore be written, provisionally, as $C_6H_6O(OH)_4$.

Nitrates, hydrogen sulphates, and other esters can also be prepared. Cellulose trinitrate, $C_6H_7O_2(NO_3)_3$, is a highly explosive compound. It is often (wrongly) called "tri-nitro-cellulose," or "gun cotton." The hydrogen sulphate, $C_6H_8O_3(SO_4H)_2$, is very unstable. It is produced only by the action of concentrated acid which rapidly resolves the compound into dextrine, and this into dextrose, which is then dehydrated and charred.

All the esters are easily saponified. On addition of water a highly hydrated form of cellulose is precipitated as a colloidal jelly containing an indefinite amount of water. (Cf. hydrates of silica, alumina, etc.).

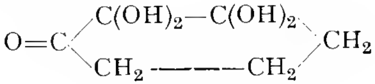
More dilute nitric acid, sp. gr. 1·2, converts cotton into a compound called oxycellulose, which, on analysis, is found to correspond to the formula, $C_{18}H_{26}O_{16}$. Comparing this with $3(C_6H_{10}O_5) = C_{18}H_{30}O_{15}$, it will be seen that oxycellulose contains more oxygen and less hydrogen in proportion to carbon than the original compound. Oxycellulose is a definite compound and forms a trinitrate, $C_{18}H_{23}O_{13}(NO_3)_3$. It appears, therefore, that either the molecule of the original cotton contains 18 atoms of carbon—if not, the $C_6H_{10}O_5$ groups have been condensed—or a more complex molecule has been broken down. Other reagents, *e.g.* chlorine, chromic acid, and permanganate of potash, also convert cotton into oxycellulose. When oxycellulose is distilled with hydrochloric acid, sp. gr. 1·06, it yields furfural.



Dilute alkalis have little or no effect upon cotton, but more concentrated solutions combine with it, forming alkali cellulose, $C_{12}H_{20}O_{10} + 2NaOH$. This compound is completely decomposed by water, and partially by alcohol. With the latter reagent only half the alkali is removed.

Cotton cellulose dissolves readily in ammonia cupric oxide,[1] and is reprecipitated in the gelatinous form on neutralising the ammonia with acids, or even by diluting with water. It is also dissolved by concentrated (40 per cent.) solutions of zinc chloride, and is reprecipitated on diluting. The precipitated hydrates give a blue coloration with iodine. A reagent made by adding iodine dissolved in potassium iodide to the zinc chloride solution gives the blue colour by direct action on the cellulose.

Judging from the various reactions and properties of the compound, Cross and Bevan[2] have proposed the following formula as probably representing the constitution of the cellulose molecule :—



It is probable, however, that it may be a multiple or aggregate of such groups.

Flax is not a simple substance like cotton, but a combination. It is perfectly homogeneous, but when boiled with alkali solutions it is resolved into cellulose and a mucilaginous product called pectic acid. The cellulose is practically identical with that of the cotton type in all except that it is slightly less resistant to the action of hydrolytic agents. The original flax appears to be a genuine chemical compound —not a mere adventitious association—of this cellulose with the group which is hydrolysed to pectic acid.

Such compounds are of common occurrence in plants and form a natural sub-group called pecto-celluloses or muco-celluloses. These substances, which are probably identical with the hypothetical pectose (p. 34), prevail in monocotyledons,

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[1] To make this reagent, freshly precipitated cupric hydrate is dissolved in strong ammonia solution.

[2] Cellulose.

and they enter largely into the composition of fruits, bulbous roots, *e.g.* turnips, etc. It may be mentioned in passing that the so-called fibre of these roots is more readily digestible by animals than the fibre of most other plants.

Jute also is a combination and of much more complex character than flax. The elementary composition is not exactly the same as that of cotton, but corresponds to the empirical formula $C_{12}H_{18}O_9$ or $2C_6H_{10}O_5—H_2O$. Jute, like flax, behaves as a homogeneous product. It is dissolved by zinc chloride solution, and by the ammonia cupric oxide reagent, and can be reprecipitated as a whole.

It is extremely resistant to the action of hydrolytic agents, but by drastic methods it can be split up into a cellulose and a non-cellulose portion. The true cellulose portion is not identical with cotton cellulose. It is not homogeneous, but consists of two kinds, one of which is less resistant to hydrolysis and to oxidation than the other. The lignone or non-cellulose portion is also heterogeneous. It contains a furfural yielding complex—probably an oxycellulose—and another group, or groups, described as keto-ring-hexenes.

Celluloses of a similar character are of common occurrence in stems and in all woody structures. They form a natural sub-group called ligno-celluloses, of which jute may be regarded as a type.

The cellulose of grasses and cereal straws consist largely of ligno-cellulose, but they differ from the typical compound in the following important particulars. They are structurally more complex, contain a smaller proportion of true cellulose, and the non-cellulose portion is relatively more susceptible to hydrolysis.

Lignification is regarded as a process of continuous modification in which the lignone gradually increases at the expense of the true cellulose, probably as a result of oxidation and dehydration. The woods, *i.e.* timber, represent the extreme limit of this process. The typical ligno-cellulose (jute) in the first year of growth contains from 70 to 80 per cent. of true cellulose, whereas the woods contain only from 50 to 60 per cent. The woods, however, are regarded as true ligno-celluloses, and all woody tissues have practically the same elementary composition notwithstanding the difference in their structural complexity.

Cork and cuticular tissues generally exercise a protective function. They are adapted to resist the action of air (oxygen) and water. Ordinary cork is made up of a complex mixture of oils, waxes, tannins, nitrogenous compounds, and the cork substance proper. The former can be separated from the last by mechanical solvents, *e.g.* alcohol, ether, etc. They are, therefore, merely mixed with the cork, but their presence greatly increases its power of resisting the natural forces of disintegration.

The cork substance proper contains cellulose of the cotton type, ligno-cellulose and two characteristic compounds called respectively cerine, $C_{20}H_{32}O$, and suberine, $C_{22}H_{42}O_3$. The latter are fatty or waxy products. They are not removable by mechanical solvents, but are saponifiable by drastic methods of oxidation and treatment with alkalis.

Crude Fibre.—In the ordinary analysis of feeding stuffs, the carbohydrates are classed as soluble carbohydrates and crude or woody fibre. The former includes the starch, sugars, gums, mucilages, and all the easily hydrolysable compounds. They are estimated by the method of difference.

To estimate the crude or woody fibre, the substance is extracted with ether to remove the fat, then boiled first with dilute acid, and afterwards with dilute alkali solution. The insoluble residue which remains is next dried and incinerated, and the loss is called crude fibre.

The method is purely conventional. The results do not correspond to the total cellulose in the material. They do not even show the amount of indigestible cellulose. It was at one time thought that they did, but more recent investigations have shown that some proportion of this crude fibre is always digested by animals. The results are not, however, entirely without value. They serve to distinguish, roughly, between those feeding stuffs which contain a large proportion of the more resistant compounds, which are more difficultly digestible, and those which contain a smaller proportion. It is considered probable that that portion of the crude fibre which is actually digested by the animals has the same nutritive value as the so-called soluble carbohydrates.

Dextrine.—Dextrine is obtained as a colourless glassy mass, or as a white amorphous powder, when perfectly dry. It is readily soluble in water, but cannot be crystallised. The solutions are colourless, tasteless and odourless, and are optically active, $[\alpha]_D = +200°$ approximately. Dextrine is insoluble in alcohol and is, therefore, precipitated from aqueous solutions by this reagent. It gives no coloration with iodine and does not reduce[1] Fehling's solution.

The elementary composition of the substance corresponds to the simplest formula, $C_6H_{10}O_5$. It is said to yield a dinitrate, $C_6H_8O_3(NO_3)_2$, and other esters. On hydrolytic treatment it yields maltose, which is further rapidly resolved into dextrose.

$$2C_6H_{10}O_5 + H_2O \rightarrow C_{12}H_{22}O_{11}$$
$$C_{12}H_{22}O_{11} + H_2O \rightarrow 2C_6H_{12}O_6$$

It is not directly fermentable by yeast; but in the presence of diastase, which converts it into dextrose, it undergoes alcoholic fermentation.

As hydrolytic treatment does not generally tend to produce condensation, but, on the contrary, to cause disintegration of complex molecules, it is probable that the molecule of dextrine contains at least $2(C_6H_{10}O_5)$. As a matter of fact the formula is often written as $C_{12}H_{20}O_{10}$. The exact molecular weight, however, is uncertain and the constitution is very obscure. It may be regarded as an intermediate compound between starch and maltose. At least three different modifications are known, and there is evidence that others can exist. Some of these have recently been obtained in crystalline form.

There is some uncertainty regarding the occurrence of dextrine in the sap of plants, but it is probably produced in the process of germination of starchy seeds, and by the mastication of starchy foods by animals. No doubt exists

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[1] The commercial product always contains sugars which reduce Fehling's solution.

that dextrine is digestible and that it has much the same nutritive value as other carbohydrates.

Dextrine may be obtained by diastatic fermentation of starch at 62° C. for about 15 minutes; the solution, after being filtered and concentrated by evaporation, is precipitated by alcohol. The commercial product, prepared by moistening starch with dilute (2 per cent.) nitric acid, allowing it to dry in the air and then heating to 110° C., is used as a substitute for gum.

Glycogen.—Glycogen is a white amorphous powder, soluble in water but insoluble in alcohol. It is optically active, $[\alpha]_D = 203\text{–}220$. It gives a bright red colour with iodine, but does not reduce Fehling's solution. Diastase converts it into maltose, boiling with dilute acids converts it into dextrose. Glycogen is one of the few carbohydrates produced by animals, and its presence only marks a stage in the transformation of other compounds. It is found in the blood and muscles, especially in embryonic tissues, and in larger quantities in the liver of animals which have recently partaken of food. The liver ferments convert it rapidly into dextrose.

Inulin.—Inulin resembles starch in many respects, and appears to replace it in certain plants chiefly belonging to the order compositæ. It is readily soluble in hot water, but practically insoluble in cold. It separates from hot aqueous solutions on cooling and is precipitated also by addition of alcohol. It is most readily obtained from the milky juice expressed from dahlia tubers and dandelion roots from which it separates in the form of minute white grains on standing. It may be purified by re-solution and precipitation. Inulin does not reduce Fehling's solution, and it gives no coloration with iodine. On prolonged boiling with water, or more rapidly in the presence of acids, it is completely hydrolysed to fructose (lævulose).

Gums.—The true gums, as distinct from dextrine, exude from the stems and twigs of certain trees, or are extracted from the same by means of solvents. They are all amorphous, transparent substances, insoluble in alcohol, but are soluble or become gelatinous when mixed with cold or hot water

They give no coloration with iodine and do not reduce Fehling's solution. They occur in cereal grains, and straws, and in other plants, are digestible by animals, and probably have the same nutritive value as dextrine and other carbohydrates. Several varieties of gum are known. The two described below may be taken as typical of the group.

Gum arabic is completely soluble in water. It forms a viscous solution from which it is reprecipitated by alcohol. It usually contains about 12 per cent. of water which is driven off at 100° C. On incineration it yields about 3 per cent. of ash, consisting chiefly of the carbonates of potassium and calcium. The basic elements can be eliminated by the action of hydrochloric acid on aqueous solutions; and on adding alcohol the arabic acid, or arabin, is precipitated. When purified by reprecipitation, the elementary composition of this substance corresponds to the formula, $C_{12}H_{22}O_{11}$ or $2C_6H_{10}O_5 + H_2O$. It is, however, a mixture of at least two compounds, one of which is lævo-rotatory and on hydrolysis with acids yields a crystallisable pentose, $C_5H_{10}O_5$, called arabinose; the other, which is dextro-rotatory, is converted into an uncrystallisable sugar. Arabinose is an aldose, $CH_2(OH).(CH.OH)_3.CHO$, and can be oxidised to arabonic acid.

When arabic acid (arabin) is heated, or treated with concentrated sulphuric acid, it is changed into an insoluble form called meta-arabic acid. By the action of alkalis this substance is reconverted into a soluble salt very similar to the original gum arabic.

Gum tragacanth, when treated with warm water, undergoes only a partial solution. The soluble portion resembles gum arabic, but is not identical with it. The insoluble portion, which is known as bassorin, absorbs water and swells up, forming a jelly very similar to meta-arabic acid.

Mucilage.—The mucilages have not hitherto been closely investigated and form a very ill-defined group. By some authors they are regarded merely as varieties of gum. They are practically insoluble in water, but swell up, forming jellies like meta-arabic acid. Several of these jellies give a blue coloration with iodine. The composition of the dry substance, free from ash constituents, corresponds approximately to the formula, $C_6H_{10}O_5$. Quince seed mucilage, on hydrolysis with dilute sulphuric acid,[1] yields (1) an insoluble portion (cellulose), (2) a soluble portion precipitated by alcohol (gum), and (3) glucose which is not precipitated by alcohol.

The mucilaginous products obtained by hydrolysis of pecto-celluloses (p. 29) are precipitated from solution on addition of alcohol in the form of a white, tasteless, stringy, gelatinous mass called pectin. It shrinks greatly on drying, and becomes very brittle. On prolonged boiling with water it changes into an insoluble form called pectic acid. This is the essential constituent of fruit jellies and jams. On further boiling, the pectic acid dissolves and the solution, which has a sour taste and reddens litmus, gives no precipitate with alcohol. This product is called meta-pectic acid.

The hypothetical mother substance, pectose, from which pectin, pectic acid, and meta-pectic acid were supposed to be derived, may now be regarded as identical with the actual pecto-celluloses. These probably occur in unripe fruits, and are gradually changed into pectic acid and meta-pectic acid as the fruit becomes first ripe and then rotten.

Substances which, like gums and mucilages, yield pentose sugars on hydrolysis are called pentosanes to distinguish them from the amyloses which yield hexose sugars, and are therefore called hexosanes. The pentosanes yield furfural on boiling with hydrochloric acid.

$$C_5H_{10}O_5 \rightarrow C_5H_4O_2 + 3H_2O.$$

(Cf. Oxycelluloses, p. 28.)

APPENDIX TO CHAPTER III

OPTICAL ACTIVITY

ANY substance which causes rotation of the plane of polarised light is said to be optically active. This property has been observed only in substances which contain an asymmetric carbon atom, *i.e.*

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[1] Cross and Bevan.

one which is united to four different groups of atoms in the molecule. Many such substances exist in three isomeric forms—one dextro-rotatory, one lævo-rotatory, and one inactive. The last is probably a compound of the other two. Mixtures, in equal proportions, of the first and second are also inactive. The optical activity of one neutralises that of the other.

Optical activity is measured by means of a polariscope. This instrument is made in several different forms, but they all consist essentially of two Nichol's prisms placed at opposite ends of a metal tube. One of the prisms, called the polariser, is fixed in position and the light which passes through it is polarised. The other, called the analyser, is movable, and when adjusted so that the corresponding axes of the two prisms are parallel, the polarised light is transmitted by it, and the field appears as a luminous disc. When the prisms are crossed, *i.e.* adjusted so that the corresponding axes are at right angles, no light is transmitted by the second prism and the field is not illuminated.

If, now, a tube containing a solution of an optically active substance be introduced between the two prisms, so that the polarised light passes through the solution, the field will be again illuminated, though the prisms remain crossed, owing to the rotation of the plane of the polarised light. The analysing prism is now turned round till the field is again obscured, and the angle through which it has been turned is measured on a divided circle attached to the instrument. This angle is called the angle of rotation. The arrangement of the prisms and tube containing the solution is shown diagrammatically in Fig. 3, and the external appearance of the instrument in Fig. 4.

As it is difficult to determine exactly the points of maximum and minimum illumination, a "half shadow" device has been introduced into the more modern instruments. The appearance of the field in this form of apparatus is shown in Fig. 5. If the prisms are not properly adjusted, one-half of the disc appears darker than the other, and the neutral point is found by turning the analyser till the two halves are equally illuminated. The introduction of the optically active substance again causes the appearance of the half shadow, and the angle of rotation is determined by turning the analyser till the shadow disappears.

The angle of rotation α is proportional to the density of the solution and the length of the column through which the polarised light passes. For purposes of comparison it is usual to consider the degree of rotation produced by a solution containing one gram of the substance in each c.c. in a tube one decimetre

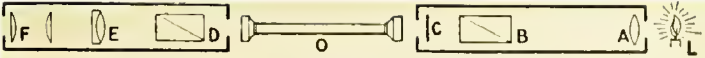


FIG. 3.

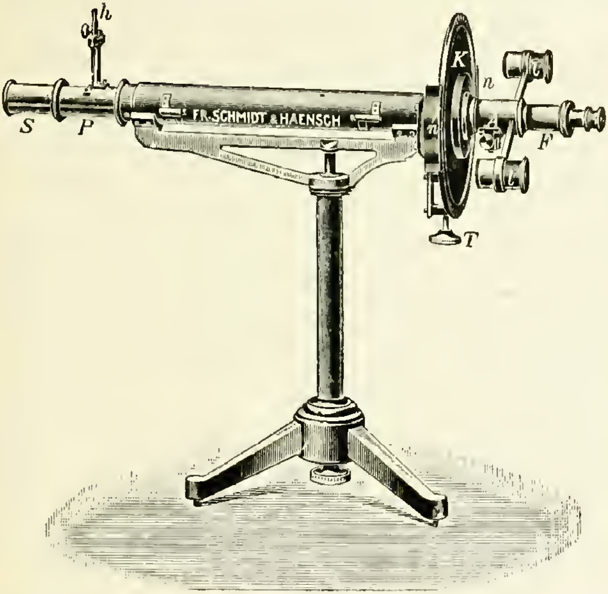


FIG. 4.

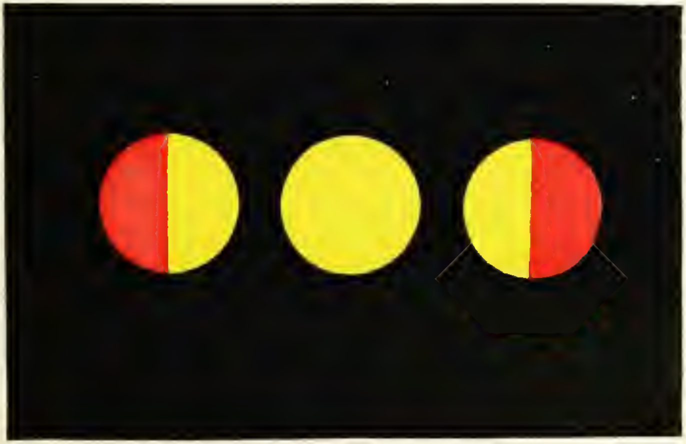


FIG. 5.

long. This angle is called the specific rotary power of the substance. It is designated by the symbol $[\alpha]_D$ when the rotation is referred to the D line of the monochromatic light produced by holding a spoon containing sodium chloride in the flame of an ordinary Bunsen burner. The specific rotary power of each optically active substance is a constant quantity (apart from the phenomena of birotation, p. 22) and the direction may be indicated by the symbols + and − according as it is dextro or lævo rotation. For example, the specific rotatory power of cane sugar is given as $[\alpha]_D = +66{\cdot}5^\circ$. The specific rotatory power of some substances varies considerably at different temperatures.

CHAPTER IV

FATS AND FIXED OILS

General Properties.—Fats and oils are two names for one and the same class of compounds. In popular language, those members of the group which are solid at ordinary temperatures are called fats, and those which are liquids under like conditions are called oils. By comparatively slight changes of temperature fats are changed into oils and *vice versâ*. Those of which the melting point is about 15° C. (the ordinary temperature) naturally assume the condition of fats in winter and of oils in summer.

Waxes and volatile oils are not included in this group. They resemble the fats and fixed oils more or less closely as regards solubility and other external properties, but are clearly distinguished from them by difference in chemical composition.

Fats and oils are obtained both from plants and animals. In the latter they form a not inconsiderable part of the tissue substance. They take rank as one of the most important classes of compounds produced exclusively by agricultural methods. Fats have been prepared synthetically, but the processes are of scientific interest only. They are easily assimilated by animals and have a higher fuel value (p. 120) than any other constituent of the food. They are used also for many other purposes, and, in accordance with the laws of supply and demand, they command a relatively high price in the market.

Fats and oils are all unctuous or greasy substances of low specific gravity—they are all lighter than water—and of variable but relatively low melting point. When pure, they are colourless or pale yellow in the liquid state, and white in the solid condition. They make a permanent translucent stain on paper and are, therefore, easily distinguished from volatile oils. The latter make a similar stain on paper, but it disappears on gentle warming.

The fats and oils are all insoluble in water; and, with few exceptions, they are also insoluble in alcohol. They are, however, readily soluble in ether, chloroform, carbon bisulphide and the lighter hydrocarbons, and they are freely miscible with each other.

Chemical Composition.—The common fats and oils are composed of the elements carbon, hydrogen and oxygen only, and these elements are present in nearly but not exactly the same proportions in all.

They undergo saponification, *i.e.* when boiled with alkalis they are converted into soaps and glycerine. By the action of superheated steam, they yield fatty acids and glycerine. Under certain conditions a similar decomposition is produced by the action of ferments. It is evident, therefore, that the natural fats are glycerides (glycerine esters) of the fatty acids. This is further proved by the fact that when glycerine and fatty acids in due proportion are heated together in sealed tubes to temperatures between 200° and 300° C., they combine, forming fats and water. If the acid radicles be designated for the present by the symbol $\bar{A}$, these changes can be represented by simple equations as follows :—

$$\underset{\text{(Fat.)}}{C_3H_5\bar{A}_3} + 3KOH \rightarrow \underset{\text{(Soap.)}}{3K\bar{A}} + \underset{\text{(Glycerine.)}}{C_3H_5(OH)_3}$$

$$C_3H_5\bar{A}_3 + 3H_2O \rightarrow \underset{\text{(Fatty acids.)}}{3H\bar{A}} + C_3H_5(OH)_3$$

As stated above, the last reaction is, under suitable conditions, reversible.

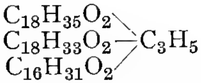
The alkali soaps are soluble in water; the calcium, lead, and other soaps are insoluble. They all react with sulphuric acid, forming the corresponding sulphates and free fatty acids according to the equation—

$$K\bar{A} + H_2SO_4 \rightarrow KHSO_4 + H\bar{A}$$

The fatty acids so obtained are exactly similar to those produced from the same fats by direct saponification with steam. They are for the most part non-volatile, and insoluble in water. Their solubility in other reagents resembles that of the original fats.

The fatty acids obtained from the natural fats are not single pure substances but mixtures of several. Stearic acid, $C_{18}H_{36}O_2$, palmitic acid, $C_{16}H_{32}O_2$, and oleic acid, $C_{18}H_{34}O_2$, are of very common occurrence. One of them may predominate, but usually all three are present. Jointly, they form over 90 per cent. of the fatty acid of all the common natural fats, and the properties of the latter are determined to a large extent by the relative proportions in which the three acids referred to enter into their composition. The presence of other fatty acids, even in small proportion, often imparts peculiar properties to particular fats.

The natural fats are often regarded as mixtures of the glycerides of the several acids, *e.g.* tristearin, $(C_{18}H_{35}O_2)_3C_3H_5$, triolein, $(C_{18}H_{33}O_2)_3C_3H_5$, tripalmitin, $(C_{16}H_{31}O_2)_3C_3H_5$. It is possible that such mixtures may exist to some extent, but it is more probable that, so far as the main bulk of the fat is concerned, the glycerine radicle is combined with two or three different acids, thus—



$$\left.\begin{array}{l} C_{18}H_{35}O_2 \\ C_{18}H_{33}O_2 \\ C_{16}H_{31}O_2 \end{array}\right\rangle C_3H_5$$

(Glycerine, stearate, oleate, palmitate.)

The Fatty Acids.—Oleic acid melts at 14° C., stearic acid at 69·2° C., and palmitic acid at 62° C. The melting points of the glycerides, triolein, tristearin, and tripalmitin, are estimated to be a little lower, viz. 2·4° C., 68·2° C., and 69° C. respectively. Olein does not solidify at temperatures above −5° C. It is evident, therefore, that the melting points of the natural fats will vary according to the relative proportions in which these three acids enter into their composition. The difference between the melting points of stearic and palmitic acids is comparatively small, but the melting point of oleic acid is much lower. Oleic acid predominates in the so-called oils, *e.g.* olive oil, and in the solid fats of lower melting point. Stearic and palmitic acids enter more largely into the composition of the harder fats, *e.g.* tallow, suet, etc.

It is important to notice that the melting points of the natural fats are not absolutely constant, but they vary only within comparatively narrow limits. For instance, butter fat usually melts at about 33° C., but some butters are a little harder or softer than others, and the difference is attributed to slight variations in the relative proportions of oleic to stearic and palmitic acids.

Stearic and palmitic acids are saturated compounds of the same homologous series as acetic acid. The constitutional formulæ of these substances are given as follows :—

$CH_3.(CH_2)_{16}.COOH$ (Stearic acid.)

$CH_3.(CH_2)_{14}.COOH$ (Palmitic acid.)

Oleic acid is an unsaturated compound. It contains two atoms of hydrogen less than stearic acid. There are, therefore, blanks on two of the carbon atoms which are united by an olefine union commonly represented by a double bond as follows :—

$$CH_3.(CH_2)_7.CH{=}CH.(CH_2)_7.CO.OH$$

(Oleic acid.)

Like all such compounds it can form addition products with halogens, *e.g.* $C_{18}H_{34}O_2Br_2$ dibromo-stearic acid. Mild oxidising agents convert it into dihydroxy-stearic acid. By the action of nitric acid and other powerful oxidising agents the molecule is split up into compounds of lower molecular weight. Nitrous acid converts oleic acid into an isomeric form called elaidic acid, which is solid at ordinary temperatures, and melts at about 45° C.

The following are the more important acids which enter into the composition of various natural fats :

(1) Saturated compounds of the acetic series, ($C_nH_{2n}O_2$).

Name.	Formula.	Melting point.
Butyric acid	$C_4H_8O_2$	—2° C.
Caproic acid	$C_6H_{12}O_2$	—1·5° C.
Capryllic acid	$C_8H_{16}O_2$	16·5° C.
Capric acid	$C_{10}H_{20}O_2$	31·4° C.
Lauric acid	$C_{12}H_{24}O_2$	43·5° C.
Myristic acid	$C_{14}H_{28}O_2$	53·8° C.
Palmitic acid	$C_{16}H_{32}O_2$	62·0° C.
Stearic acid	$C_{18}H_{36}O_2$	69·2° C.
Arachidic acid	$C_{20}H_{40}O_2$	75·0° C.
Behenic acid	$C_{22}H_{44}O_2$	83·0° C.

All these, from butyric acid to stearic acid, inclusive, enter more or less largely into the composition of butter fat. Some of them are present only in very small proportion, but butyric acid, it is estimated, forms something like 5 per cent. of the whole; and as it is absent, or occurs only in very small proportion in other fats, butter fat can be distinguished readily and certainly from all others in this way (p. 26). The butyric acid can be separated more or less completely from the others either by solution in water or by distillation.

Arachidic acid is a characteristic ingredient of oil of earthnuts (*Arachis hypogea*). It appears to be practically identical with the theobromic acid obtained from cocoa butter, but the latter melts at a slightly higher temperature, 75° C.

(2) Unsaturated acids.

(A) Series $C_nH_{2n-2}O_2$. The only important representative of this class is oleic acid, ($C_{18}H_{34}O_2$), which has already been described. It is a constituent of nearly all the common fats, but predominates in those of lower melting point—the oils—which are chiefly of vegetable origin.

(B) Series $C_nH_{2n-4}O_2$. The most important member of this series is linoleic acid, $C_{18}H_{32}O_2$. It enters largely into the composition of linseed, hemp, poppy, and nut oils, and it occurs also, in smaller quantity, in olive oil, rapeseed oil, fish oils, etc.

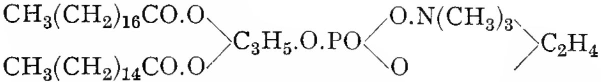
(C) Series $C_nH_{2n-6}O_2$. The most important member of this series is linolenic acid, $C_{18}H_{30}O_2$. It occurs along with linoleic acid in linseed, cotton seed, and other vegetable oils.

Drying Oils.—All these unsaturated compounds are capable of forming addition products with halogens, oxygen, hydrogen, hydroxyl, etc., and this property is retained also by the salts and glycerides. The amount of iodine which a fat can absorb is therefore a measure of the amount of unsaturated acid in it. This value—the "iodine number"—is approximately constant for any given natural fat, and forms one of the most important means of identifying them. According to the formulæ, two parts of linolenic acid can absorb, *i.e.* combine with, as much iodine as three parts of linoleic acid, or six parts of oleic acid. The compounds formed are of course halogen substitution products of stearic acid.

Oleic acid, linoleic acid, and linolenic acid, when saturated with hydrogen, all form stearic acid. By addition of oxygen or hydroxyl, oxy or hydroxy stearic acids are produced. Such compounds are formed on exposure to air—more rapidly at higher temperatures—and by the action of mild oxidising agents. The products are solid substances of a resinous character. Oils which contain much unsaturated acids have the property of drying. Linseed oil exhibits this character in very marked degree, and is therefore largely used as a medium in the preparation of paints. Those which contain smaller quantities of unsaturated acids are described as semi-drying oils. The drying property is not noticeable in oils which contain even considerable quantities of oleic acid, but no linoleic or linolenic acids.

Hempseed, poppy seed, and sunflower seed oils are classed as drying oils; those of cotton seed, rape seed (colza), sesame, soja bean, maize, and beechnuts are classed as semi-drying oils; while earthnut oil (arachis), almond oil, and olive oil are typical non-drying oils.

Compound Types.—Lecithin is a wax-like substance which occurs normally in nerve and brain tissues, in the yolk of egg, butter, and many vegetable oils. It is soluble in ether and other fat solvents, and also in alcohol. It has the peculiar property of uniting both with acids and with bases (p. 50) to form salts. It is often described as a phosphorised fat, because, on saponification, it yields stearic and palmitic acids, choline and glycero-phosphoric acid. It is, therefore, regarded as a compound type, *i.e.* a glyceride of stearic and palmitic acids, in which the third hydroxyl of the glycerine is replaced by the phosphoric acid radicle in ethereal combination with choline (p. 56). This constitution is indicated by the following formula :—



$$\left.\begin{array}{l} CH_3(CH_2)_{16}CO.O \\ CH_3(CH_2)_{14}CO.O \end{array}\right> C_3H_5.O.PO \left< \begin{array}{l} O.N(CH_3)_3 \\ O \end{array} \right> C_2H_4$$

(Lecithin.)

Rancidity.—Fats, when exposed to air, exhibit a tendency to become rancid. This tendency is not confined to any one group or class, but is common to those of vegetable and of animal origin alike. The tendency is, however, much more pronounced in some, *e.g.* palm oil, butter, etc., than in others.

Primarily, no doubt, this change consists in the partial saponification of the fat by the action of micro-organisms or of enzymes. The free fatty acids produced have an extremely disagreeable taste, and those which are volatile, *e.g.* butyric acid, have also a very offensive odour. It is probable, however, that secondary changes also occur, resulting in the oxidation of the unsaturated portion, if any, and the partial oxidation of the glycerine to aldehydes and acids of a more or less volatile character.

Natural Fats.—There is no essential difference between animal and vegetable fats except as regards their origin. Both consist of the glycerides of fatty acids—mainly oleic, stearic, and palmitic acids. In the animal, fat forms part of the tissue substance. It occurs in layers or masses in various parts of the body, but especially in the region of the kidneys which it surrounds and encloses. Small quantities of fat are intimately associated with the muscular tissues. Beefsteak, free from all visible fat, was found to contain from 1 to 3 per cent. of that ingredient. The organic matter of bones also includes a considerable quantity of fat.

Beef and mutton suet, when dried and separated from skin and other adventitious impurities, are popularly called tallow. Hog's fat, similarly purified, is called lard; it has a somewhat lower melting point than tallow, owing to the larger proportion of olein which it contains.

Melted tallow and other fats gradually resolidify on cooling, and a partial separation of the ingredients can be effected by pouring off the more liquid portion. The final products obtained by repeating this process several times, differ considerably as regards their melting points, but they are not even approximately pure glycerides.

Fats do not form part of the tissues of plants as they do in animals. They are chiefly stored up in the seeds as nourishment for the embryo, but they occur also, in smaller quantities, in the vegetative organs.

The vegetable fats are extracted from seeds (*a*) by the application of heat and pressure, (*b*) by means of solvents. Oily seeds may contain from 40 to 50 per cent. of oil, and from 60 to 80 per cent. of the whole is removed in the former process. The compressed residues therefore contain about 10 per cent. of oil, and are correspondingly richer than the original seeds in all other ingredients. They are called oil cakes (p. 273), and are largely used for feeding cattle.

When the oil is extracted by means of solvents, the residue is obtained in the form of a meal or powder. The solvents remove a larger percentage of the fat; the residual meals, therefore, as a rule, contain a smaller proportion of that ingredient, and, of course, a correspondingly larger proportion of the others.

The crude fats extracted from the seeds are purified by processes of filtration, oxidation, reduction, washing with water, acids, alkalis, exposure to heat, light, etc., as the particular case may require.

The natural fats are not simple pure glycerides, but mixtures, and their composition and properties are not absolutely constant, but only approximately so. It is, therefore, often very difficult to identify any given sample of fat of unknown origin. When several are mixed together it is usually impossible to determine with certainty which of the various natural fats have been introduced, or in what proportions they are present. If, however, the properties of the mixture are known, it is not, as a rule, very difficult to concoct another to match the sample in all essential particulars.

Qualitative Tests.—The more important properties upon which chemists are accustomed to rely for these purposes are the colour, taste, smell, viscosity, specific gravity, melting point, amount of alkali required for saponification, the iodine number, the rise of temperature on treatment with sulphuric acid, the action of nitrous acid and of chloride of sulphur, and certain colour reactions with sulphuric acid, nitric acid, etc.

Quantitative Determination. — The methods employed for the quantitative determination of fat in vegetable products all depend, ultimately, on the complete extraction of the fat from the sample by means of solvents. Common ether or the so-called petroleum ether (a mixture of the lighter paraffins) is generally used. The Soxhlet extraction tube is perhaps the most convenient form of apparatus for this purpose. Many different modifications have been introduced from time to time, but the original, shown in the illustration (Fig. 6), has never been superseded. The extracted fat may either be weighed directly, after evaporating off the ether, or it may be deduced from the loss found by weighing the residue after drying.

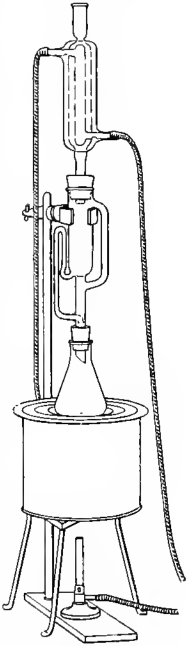


FIG. 6.—Soxhlet's apparatus.

The result obtained by this process does not represent pure fat; it includes chlorophyll, waxes, and other substances soluble in ether. It is called "crude fat" or "ether extract."

CHAPTER V

NITROGENOUS COMPOUNDS

(*Amides*)

THE nitrogenous compounds found in plants and animals—apart from nitrates and ammonium salts which do not occur in any considerable quantities—may be broadly divided into two principal groups, viz. proteins or albuminoids and amides. The two groups are very closely allied. The distinction between them is ultimately an arbitrary one; but, in general, the former are colloids and are coagulated by heat and by various reagents, whereas the latter are crystalline and are not so coagulated. The members of each group are derived theoretically and, to some extent at least, actually, from those of the other. They enter into the composition of all the common foods to a greater or less extent, and play a prominent and peculiar part in animal nutrition. Both groups include a large number of different compounds and the majority are very complex in character.

Types.—In general chemistry, the term "amide" is reserved for compounds of the type of acetamide ($CH_3.CO.NH_2$). This, it will be seen, may be regarded either as acetic acid in which the hydroxyl is replaced by NH_2, or as ammonia (NH_3) in which an atom of hydrogen is replaced by the acid radicle (CH_3CO).

The acid radicles may, of course, be replaced by alcohol radicles. The compounds so produced are generally called amines. They are similar in many respects to the amides. If ethylamine ($CH_3.CH_2.NH_2$) be taken as typical of the amines, the essential difference between the two groups will be recognised on comparison of the formulæ.

The hydroxy acids, *e.g.* glycollic acid, $CH_2(OH).CO.OH$, exhibit the characteristic properties of alcohols as well as of acids, and either or both of the hydroxyls may be replaced by NH_2. Three different types are thus derived as follows:—

$CH_2(NH_2).CO.OH$ (Amino-acetic acid.)

$CH_2(OH).CO.NH_2$ (Hydroxyacetamide.)

$CH_2(NH_2).CO.NH_2$ (Aminoacetamide.)

These compounds, it will be noticed, may be referred either to the type of amines or of amides previously mentioned or to both at once.

If the amines and amides be classed together, the whole group may be indicated generally by the formulæ RNH_2, in which R stands for any alcohol radicle or acid radicle whatever. It is convenient to regard them here as substituted ammonia derivatives because the process of replacement can be continued further, and compounds of the general types R_2NH, R_3N, and even R_4NOH (derived from NH_4OH) can be obtained. It is scarcely necessary to add that when more than one radicle is present in a compound they are not necessarily, or usually, the same.

In agricultural chemistry the term "amides" is often loosely applied to all compounds which belong to any of these types. There is, however, one important point of difference between the compounds of the acid radicles, such as acetamide, and those of the alcohol radicles, *e.g.* ethylamine. The former are easily saponified by the action of acids and alkalis according to the equation below; the latter are not.

$$CH_3.CO.NH_2 + H_2O \rightarrow CH_3.CO.OH + NH_3$$

General Properties.—The amides proper, *e.g.* acetamide, are neutral crystalline substances, generally soluble in water, alcohol, etc. They can be prepared in many cases by gently heating the ammonium salts of the corresponding acids, thus—

$$CH_3.CO.ONH_4 \rightarrow CH_3CO.NH_2 + H_2O$$

On further heating with dehydrating agents they lose a second molecule of water and are converted into nitriles.

$$CH_3.CO.NH_2 \rightarrow CH_3CN + H_2O$$

By addition of hydrogen, nitriles are converted into amines.

$$CH_3CN + 2H_2 \rightarrow CH_3.CH_2.NH_2$$

Amines, of the type of ethylamine, retain the basic character of ammonia. The lower members of the series are soluble in water, have a strongly alkaline reaction, and combine with acids to form salts.

$$CH_3.CH_2.NH_2 + HCl \rightarrow CH_3.CH_2.NH_3Cl$$

These salts are generally soluble in water, neutral and crystalline. They may be regarded as ammonium chloride in which an atom of hydrogen is replaced by the alcohol radicle.

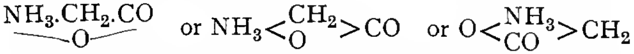
Amino-acids, *e.g.* amino-acetic acid, belong to two types at once. They have the basic properties of the amines proper and also the acidic properties of the original acids. They can therefore form salts both with acids and with bases.

$HO.OC.CH_2(NH_2)$ (Glycocine.)

$HO.OC.CH_2(NH_3)Cl$ (Glycocine hydrochloride.)

$CH_2(NH_2).CO.ONa$ (Sodium glycocolate.)

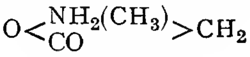
But these two kinds of properties are incompatible; the one neutralises the other, and the compounds are neutral, soluble, crystalline, salt-like bodies. There is reason to believe that this condition arises from an actual combination of the acidic with the basic part, *i.e.* that the hydrogen of the acid is transferred to the nitrogen, and the latter is joined to the oxygen of the acid, as in the case of ammonium salts ($NH_4.O.NO_2$). The formula of glycocine is not therefore generally written as $NH_2.CH_2.CO.OH$, but as



$$\underset{\smile O \smile}{NH_3.CH_2.CO} \quad \text{or } NH_3<\substack{CH_2\\O}>CO \quad \text{or } O<\substack{NH_3\\CO}>CH_2$$

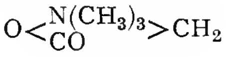
By replacing one or more of the hydrogen atoms in the

(NH_3) group by (CH_3), or other alcohol radicles, various substituted derivatives are obtained, *e.g.* sarcosine (methyl-amino acetic acid), betaine (trimethyl-amino acetic acid), etc.



$$\mathrm{O}<\genfrac{}{}{0pt}{}{\mathrm{NH_2(CH_3)}}{\mathrm{CO}}>\mathrm{CH_2}$$

(Sarcosine.)

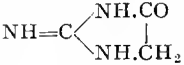
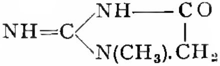
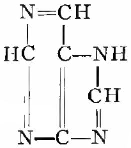


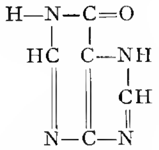
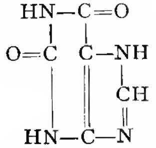
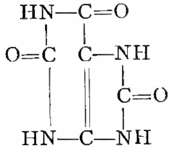
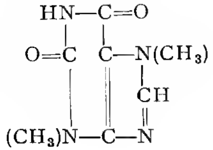
$$\mathrm{O}<\genfrac{}{}{0pt}{}{\mathrm{N(CH_3)_3}}{\mathrm{CO}}>\mathrm{CH_2}$$

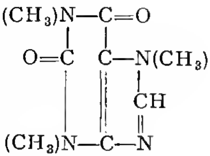
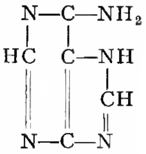
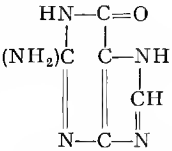
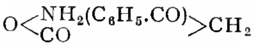
(Betaine.)

The names and formulæ of some of the more important members of the group, which occur in plants and animals, are given in the following table for purposes of comparison and reference.

Common name.	Systematic name.	Empirical formula.	Constitutional formula.
Glycocine . .	Amino-acetic acid	$C_2H_5O_2N$	$O<\substack{NH_3\\CO}>CH_2$
Sarcosine . .	Methyl glycocine . .	$C_3H_7O_2N$	$O<\substack{NH_2(CH_3)\\CO}>CH_2$
Betaine . . .	Trimethyl glycocine . .	$C_5H_{11}O_2N$	$O<\substack{N(CH_3)_3\\CO}>CH_2$
Alanine . . .	α-Amino-propionic acid . .	$C_3H_7O_2N$	$O<\substack{NH_3\\CO}>CH.CH_3$
Serine . . .	β-Hydroxy-α-amino-propionic .	$C_3H_7O_3N$	$O<\substack{NH_3\\CO}>CH.CH_2OH$
Phenyl-alanine .	β-phenyl-α-amino-propionic acid	$C_9H_{11}O_2N$	$O<\substack{NH_3\\CO}>CH.CH_2.C_6H_5$
Tyrosine . .	Hydroxy-phenyl alanine . . .	$C_9H_{11}O_3N$	$O<\substack{NH_3\\CO}>CH.CH_2.C_6H_4(OH)$
Tryptophane .	β-indole-α-amino-propionic acid	$C_{11}H_{12}O_2N_2$	$O<\substack{NH_3\\CO}>CH.CH_2.C\lessdot\substack{C_6H_4\\CH}>NH$
Leucine . . .	Amino-isobutyl-acetic acid . . Amino-caproic acid	$C_6H_{13}O_2N$	$O<\substack{NH_3\\CO}>CH.CH_2.CH(CH_3)_2$
Lysine . . .	Diamino-caproic acid	$C_6H_{14}O_2N_2$	$O<\substack{NH_3\\CO}>CH.(CH_2)_3.CH_2(NH_2)$
Aspartic acid .	Amino-succinic acid	$C_4H_9O_4N$	$O<\substack{NH_3\\CO}>CH.CH_2.CH_2.CO.OH$
Asparagine . .	Amino-succinamide	$C_4H_{10}O_3N_2$	$O<\substack{NH_3\\CO}>CH.CH_2.CH_2.CO.NH_2$

Glutaminic acid	Amino-glutaric acid	$C_5H_9O_4N$	$\mathrm{O{<}\begin{smallmatrix}NH_3\\ CO\end{smallmatrix}{>}CH.(CH_2)_2CO.OH}$
Cystine	α-diamino-β-dithio-dilactic acid	$C_6H_{12}O_4S_2N_2$	$\mathrm{O{<}\begin{smallmatrix}NH_3\\ CO\end{smallmatrix}{>}CH.CH_2.S.S.CH_2.CH{<}\begin{smallmatrix}NH_3\\ CO\end{smallmatrix}{>}O}$
Arginine	Guanidin-amino-valerianic acid	$C_6H_{14}O_2N_4$	$\mathrm{O{<}\begin{smallmatrix}NH_3\\ CO\end{smallmatrix}{>}CH.(CH_2)_3.NH.C(NH_2).NH}$
Histidine	β-imidazole-α-amino-propionic acid	$C_3H_9O_2N_3$	$\mathrm{O{<}\begin{smallmatrix}NH_3\\ CO\end{smallmatrix}{>}CH.CH_2{<}\begin{smallmatrix}NH.CH\\ CH\end{smallmatrix}{>}N}$
Urea	Carbamide	CON_2H_4	$\mathrm{O{=}C{<}\begin{smallmatrix}NH_2\\ NH_2\end{smallmatrix}}$
Guanidine	Imido-carbamide	CN_3H_5	$\mathrm{NH{=}C{<}\begin{smallmatrix}NH_2\\ NH_2\end{smallmatrix}}$
Glycocyamine	Guanido-acetic acid	$C_3N_3H_7O_2$	$\mathrm{NH{=}C{<}\begin{smallmatrix}NH_2\\ NH.CH_2.CO.OH\end{smallmatrix}}$
Creatine	Methyl glycocyamine	$C_4N_3H_9O_2$	$\mathrm{NH{=}C{<}\begin{smallmatrix}NH_2\\ N(CH_3).CH_2.CO.OH\end{smallmatrix}}$
Glycocyamidine	Glycocyamidine	$C_3N_3H_5O$	
Creatinine	Methyl glycocyamidine	$C_4N_3H_7O$	
Purine	Purine	$C_5H_4N_4$	

Common name.	Systematic name.	Empirical formula.	Constitutional formula.
Hypoxanthine	Oxypurine	$C_5H_4N_4O$	
Xanthine	Dioxypurine	$C_5H_4N_4O_2$	
Uric acid	Trioxypurine	$C_5H_4N_4O_3$	
Theobromine	Dimethyl-dioxypurine	$C_5H_2N_4(CH_3)_2O_2$	

Caffeine, or Theine .	Trimethyl-dioxypurine . .	$C_5HN_4(CH_3)_3O_2$	
Adenine .	Amino-purine .	$C_5H_3N_4.NH_2$	
Guanine . . .	Amino-oxypurine	$C_5H_3N_4.NH_2.O$	
Hippuric acid	Benzoyl glycocine	$C_9H_9O_3N$	 $O<\genfrac{}{}{0pt}{}{NH_2(C_6H_5.CO)}{CO}>CH_2$
Indole . . .	Indole	C_8H_7N	 $C_6H_4<\genfrac{}{}{0pt}{}{CH}{NH}\geqslant CH$
Skatol . . .	β-methyl-indole	C_9H_9N	 $C_6H_4<\genfrac{}{}{0pt}{}{C(CH_3)}{NH}\geqslant CH$

Occurrence.—Some of the amino compounds mentioned in the tables, *e.g.* betaine, asparagine, glutamine, are probably not formed by animals; others, *e.g.* urea, uric acid, guanine, are not known to occur in plants. Leucine, tyrosine, and some others are commonly found in the juices of both kinds of organism. They are known to be amongst the most important products of the putrefactive decay of proteins, and they are probably also formed as intermediate products in the process of digestion of these compounds by animals.

Sarcosine occurs in the juice of flesh. Betaine is produced by the oxidation of choline,  $C_2H_4{<}\substack{OH \\ N(CH_3)_3OH}$. It has been found in cotton seeds, malt, and malt coombs. It occurs in larger quantities in sugar beet, and may be recovered from the molasses.

Leucine is produced by pancreatic digestion of fibrine and other proteins. It occurs normally in the spleen and lymph-glands. Isomeric forms are present in many plants, and may be obtained from conglutin—the globulin of lupines.

Asparagine was so called because it was first obtained from asparagus. It occurs also in beetroot, peas, beans, vetches, and, generally, in all sprouting and young vegetable tissues. The asparagine and aspartic acid found in sprouting seeds is probably derived from the protein compounds which are thus transferred to the growing points and re-elaborated. It has been asserted that the proteins of plants are mainly formed by condensation of asparagine aldehyde. It is tolerably certain, however, that other amino compounds, *e.g.* tyrosine, tryptophane, etc., which contain benzene rings take part in these reactions. Cystin or other sulphur containing molecules are also necessary to complete the process.

Urea or carbamide, the amide of carbonic acid, $CO(OH)_2$, was originally discovered in urine of which it is the chief nitrogenous constituent. This means that the metabolic products resulting from the oxidation of the nitrogenous tissues are excreted chiefly in the form of urea. An adult man excretes about 30 grams of urea, over 1 oz. per day. Urea was subsequently prepared from ammonium isocyanate—a reaction to which great historical interest attaches—with which it is isomeric, $NH_4OCN \rightarrow CO(NH_2)_2$. It may also be formed by hydrolysis of cyanamide—

$$CN.NH_2 + H_2O \rightarrow CO(NH_2)_2$$

Further, hydrolytic treatment converts it first into ammonium carbamate, and this finally into ammonium carbonate—

$$CO(NH_2)_2 + H_2O \rightarrow NH_4.O.CO.NH_2$$
$$NH_4.O.CO.NH_2 + H_2O \rightarrow (NH_4)_2CO_3$$

Guanidine occurs in small quantity both in animal and vegetable products, but it is of interest chiefly on account of its relation to urea on the one hand and to uric acid, creatine, and creatinine on the other.

Uric acid, a white crystalline substance, practically insoluble in water, is the chief nitrogenous constituent of the excrement of birds and reptiles. It is found also in the muscular juices, in blood and in the urine of mammals, especially the carnivora. In the urine of herbivorous animals, hippuric acid forms a considerable proportion of the nitrogenous matter. This compound is easily resolved into glycocine and benzoic acid, C_6H_5COOH.

Alkaloids.—Xanthine is important chiefly because of its close relationship to theobromine and caffeine. These compounds are usually referred to a special class of amino bodies called alkaloids or vegetable bases.

Apart from their chemical composition and reactions, considerable interest attaches to these substances by reason of their pronounced physiological effects. Theobromine occurs in cocoa, and caffeine or theine in coffee and tea; and it is to the presence of these alkaloids that the stimulating effects of the beverages are due. Other alkaloids exert a sedative influence. They are largely used in medicine. The great majority are more or less poisonous to animals, and are distinguished by their extremely bitter taste. The presence of alkaloids in certain herbs, *e.g.* lupines, renders them distasteful to cattle, and it is said that they have been known to cause death.

The exact constitution of many of the vegetable alkaloids is unknown. They are usually classified according to their origin as follows:—

1. Opium bases.
2. Cinchona bases.
3. Strychnos bases.
4. Other alkaloids.

Opium is the dried juice of the green seeds of the poppy plant (papaver somniferum). It is a complex mixture of gummy and resinous matters with which are associated some 18 or 20 different alkaloids. The latter are present in the form of salts, chiefly of sulphuric and meconic acids. Morphine, $C_{17}H_{19}O_3N$, and narcotine, $C_{22}H_{23}O_7N$, are considered the most important in this group.

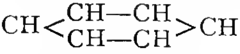
Cinchonine, $C_{19}H_{22}ON_2$, quinine, $C_{20}H_{24}O_2N_2$, and several others are obtained from the bark of various species of cinchona.

Strychnine, $C_{21}H_{22}O_2H_2$, is obtained from Nux Vomica, St. Ignatius bean, False Augustura bark, and other plants. Brucine, $C_{23}H_{26}O_4N_2$, belongs to the same group. They are all extremely poisonous.

The following may also be mentioned: atropine, obtained from Atropa Belladonna (night-shade), aconitine, from Aconitum Napellus (monkshood) and solanin from the potato plant.

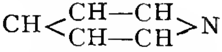
The pyridine bases, quinoline bases, and some others are also usually classed with the alkaloids, though they differ markedly both in composition and properties. These substances contain no oxygen, and can be volatilised without decomposition.

The pyridine bases form a homologous series of the general formula, $C_nH_{2n-5}N$. The constitution of the lowest member may be compared with that of benzene—



$$\mathrm{CH}<\begin{array}{c}\mathrm{CH-CH}\\ \mathrm{CH-CH}\end{array}>\mathrm{CH}$$

(Benzene.)

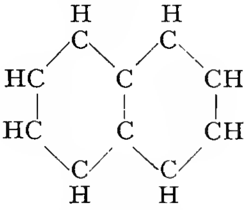


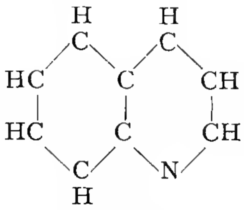
$$\mathrm{CH}<\begin{array}{c}\mathrm{CH-CH}\\ \mathrm{CH-CH}\end{array}>\mathrm{N}$$

(Pyridine.)

The other members of the series—picoline (methyl pyridine), C_6H_7N, lutidine, C_7H_9N, collidine, $C_8H_{11}N$, etc., are derived from pyridine by substitution of H by CH_3, C_2H_5, etc.

The quinoline bases also form a homologous series of the general formula, $C_nH_{2n-11}N$. The lowest member of the series bears the same relation to naphthalene as pyridine bears to benzene.


(Naphthalene.)


(Quinoline.)

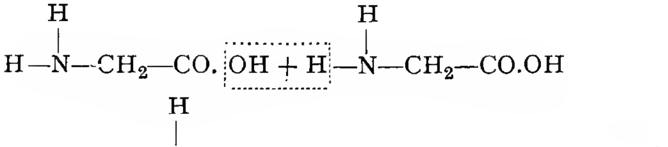
The other members of the series are derived from quinoline, C_9H_7N, by substituting CH_3 and other alcohol radicles for H. Lepidine, $C_{10}H_9N$, and cryptidine, $C_{11}H_{11}N$, are the next two.

Conine, $C_8H_{17}N$, a well-known volatile alkaloid obtained from hemlock seeds, and nicotine, $C_{10}H_{14}N_2$, which occurs in the leaves and seeds of the tobacco plant, are both extremely poisonous.

Ptomaines.—The ptomaines or toxines are another group of amino bodies closely allied to the last. They are produced by the decomposition of animal tissues by various putrefactive organisms. They have been called the alkaloids of decay. Bodies of this kind are practically innumerable, but the following may be regarded as typical.

Ethylene diamine, $C_2H_4{<}\begin{matrix}NH_2\\NH_2\end{matrix}$, is extremely poisonous. Tetramethylene diamine (putrescine), $\begin{matrix}CH_2.CH_2.NH_2\\|\\CH_2.CH_2.NH_2\end{matrix}$, and pentamethylene diamine (cadaverine), $CH_2{<}\begin{matrix}CH_2.CH_2.NH_2\\CH_2.CH_2.NH_2\end{matrix}$ are said to be non-poisonous. Neurine (ethyl-trimethyl-ammonium hydroxide), $\begin{matrix}(CH_3)_3\\C_2H_5\end{matrix}{>}NOH$, which has been prepared from brain tissue, is very poisonous, whereas choline (hydroxy ethyl-trimethyl-ammonium hydroxide), $\begin{smallmatrix}(CH_3)_3\\C_2H_4OH\end{smallmatrix}>NOH$, is non-poisonous. The last is a normal constituent of bile.

Peptides.—It has been shown (p. 50) that the amino-acids can form salts, (*a*) with acids and (*b*) with bases. As they are themselves at once acidic and basic they can form salts with each other, *i.e.* by reaction of the carboxyl group of one molecule with the amino group of another. The compound formed by the reaction of two molecules of glycocine (amino-acetic acid) is called glycyl-glycine.



$$H-\overset{H}{\overset{|}{N}}-CH_2-CO.\boxed{OH+H}-\overset{H}{\overset{|}{N}}-CH_2-CO.OH$$

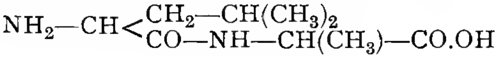
$$\rightarrow H-\overset{H}{\overset{|}{N}}-CH_2-CO-NH-CH_2-CO.OH+H_2O$$

(Glycyl-glycine.)

If the two reacting molecules are not of the same kind two different, isomeric compounds can be formed. Thus alanine and leucine combine in two different ways as shown below.

$$NH_2-CH(CH_3)-CO-NH-CH<\begin{matrix}CH_2-CH(CH_3)_2\\CO.OH\end{matrix}$$

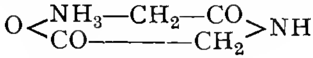
(Alanyl-leucine.)



$$NH_2-CH<\begin{matrix}CH_2-CH(CH_3)_2\\CO-NH-CH(CH_3)-CO.OH\end{matrix}$$

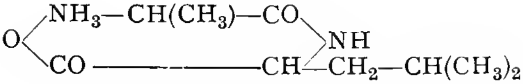
(Leucyl-alanine.)

Such compounds are called peptides. They retain the essential characteristics of the amino-acid type, *i.e.* they are neutral substances, but are potentially both acidic and basic. It is probable therefore that, like the simple amino-acids, they have a cyclic constitution which may be represented as follows:



$$\mathrm{O}<\begin{matrix}\mathrm{NH_3—CH_2—CO}\\ \mathrm{CO———CH_2}\end{matrix}>\mathrm{NH}$$

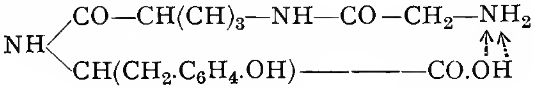
(Glycyl-glycine.)



(Alanyl-leucine.)

By a continuation of the same process, three, four, or more molecules of amino-acids may be linked up together, forming tripeptides, tetra-peptides, and so on. Those which contain only two molecules of amino-acid, *e.g.* glycyl-glycine, are called dipeptides. Theoretically there are no limits to the formation of such polypeptides. Compounds containing eighteen molecules of amino-acid have already been prepared.

The formula for glycyl-alanyl-glycyl-tyrosine—a tetra-peptide is as follows:—



The polypeptides are resolved into amino-acids on hydrolytic treatment. They are of special importance from their close relation to the proteins. The peptides may be regarded as intermediate between the peptones—the simplest proteins—and amino-acids. They are, in fact, only excluded from the protein group by the arbitrary test of the biuret reaction.

CHAPTER VI

NITROGENOUS COMPOUNDS

(*Proteins or Albuminoids*)

Occurrence.—The class of proteins or albuminoids includes a large number of compounds. Some of them are so much alike in composition and properties that it is difficult to separate them from each other, or to determine whether they are one or several substances. Others differ so widely from the typical compound as to give rise to difference of opinion whether they should or should not be included in the group.

They are widely distributed in nature, and are of the highest importance from the point of view of animal nutrition. Apart from water, they constitute the chief mass of animal bodies. They enter largely into the composition of eggs and seeds, in which they form part of the embryonic nourishment. They occur also, in solution, in the fluids—*e.g.* blood, lymph, cell sap—of both plants and animals. Physiologically, they are all closely related, and are derived from each other by complex and obscure series of chemical changes. One new compound may be formed out of several original substances, and, like the celluloses, they probably undergo organic changes subsequent to their chemical elaboration.

These compounds have not yet been synthetically prepared, and their exact molecular constitution is unknown. It is certain, however, that they are all very complex, *i.e.* they have high molecular weights, and are aggregates of many different groups of atoms. In some cases, the typical compound is associated, in definite chemical union, with a prosthetic group or non-protein radicle. These are to be regarded as compound or conjugated bodies, in contradistinction to the simple substances in which the typical compound is not so associated. Both types occur in nature.

In addition to the native proteins above referred to, the group includes a number of transformation products, derived from them by artificial means, but which retain the essential characteristics of the group.

Nomenclature.—The study of this group of substances has been greatly complicated by an unfortunate confusion in nomenclature. White of egg was long regarded as a typical member, and the terms *Eiweisskörper* (egg-white bodies) or *Proteinstoffes* were used in German as equivalent to the French *substances albuminoid.* In English, the terms "protein" and "albuminoid" have been, and are still occasionally, used in a differential sense, to distinguish between the simple and compound types, and also to distinguish between the "true or genuine" proteins, such as white of egg, and other substances, such as horn, gelatine, etc., which were not regarded as true proteins, though closely allied to them.

These substances are now regarded as members of the group, and the term "protein" has been definitely accepted as the scientific name for the whole class. The term "albuminoid" is now rarely used, except for commercial purposes, but may be regarded as an alternative name.

Physical Properties.—In the dry state, the native proteins are obtained as white or nearly colourless amorphous, non-hygroscopic powders. Some of them are soluble in pure water, others are soluble in solutions of neutral salts, or in dilute acids or alkalis. They are all insoluble in alcohol, ether, chloroform, etc., and are therefore precipitated from aqueous solution by these reagents.

The solutions of those that are soluble in pure water offer great resistance to the passage of the electric current. The boiling points and freezing points of these solutions, when they can be determined, differ very slightly from those of the solvents under similar conditions. The substances have very low osmotic pressure, they do not crystallize readily, and, under certain conditions, they are easily coagulated. In short, they exhibit the characteristic properties of colloids. Even colloids, however, though they offer great resistance, are nevertheless regarded as electrolytes. The solutions of proteins are not absolute non-conductors, and the compounds may furnish either kations or anions.

Coagulation.—The kind of change which white of egg suffers on boiling is called coagulation. Ability to undergo such change is a characteristic property of the class. Each individual compound coagulates at a particular temperature. For the majority of substances this temperature is considerably below the boiling point of water. Compounds which are very similar in other respects can often be separated in this way, *i.e.* by fractional coagulation.

The nature of the change is not well understood, but it has been found: (1) that complete precipitation occurs only when the solutions are just faintly acid. Under any other conditions, some of the substance remains in solution. The reaction of the solution changes when precipitation takes place; neutral solutions turn alkaline, and those which are acid to begin with become less acid. (2) If all inorganic salts be removed from the solution by prolonged dialysis, no precipitation takes place on warming the solutions; but if soluble salts be added to the hot solution, the coagulated protein is immediately precipitated. It is considered probable that the change actually occurs on warming the solution, and that the products are soluble in water, but are precipitated by the salt.

The changes may be due to some slight partial decomposition or dehydration, or they may indicate merely some intramolecular rearrangement.

Formic aldehyde prevents coagulation by heat. It combines with the protein. The compound has been called "methylene-albumin." Acetaldehyde acts in a similar manner, but other aldehydes cause precipitation.

Finely divided metallic silver and freshly precipitated silver oxide both prevent coagulation. This phenomenon also may be due to combination. The silver may displace an atom of hydrogen united to the sulphur of the protein, and form a soluble compound.

Proteins are precipitated from aqueous solutions on addition of alcohol. The protein, however, is not coagulated. It is apparently unchanged and may be redissolved in water. The action may be compared to the precipitation of dextrine by alcohol; in both cases it is attributed merely to the insolubility of the compound in the reagent. On prolonged contact with strong alcohol, proteins undergo a change similar to that produced by warming the solutions, they become permanently insoluble in water, and are in fact coagulated. Tannins, phenols, acetone, and several other reagents also cause coagulation.

Coagulation may also be induced by certain mechanical means, *e.g.* violent agitation, and by contact with porous substances such as charcoal and unglazed pottery.

The change which takes place naturally in fibrinogen and caseinogen—sometimes called spontaneous coagulation—is due to the action of certain ferments. It is not regarded as true coagulation because the precipitates are not so insoluble as those produced by heating the solutions. Connheim[1] has used the term *gerinung* (curdling) to describe this change.

Flocculation.—All proteins, including peptones, are completely precipitated from aqueous solutions when the latter are saturated with ammonium sulphate. Zinc sulphate may be used instead of ammonium sulphate. Many other salts, *e.g* potassium acetate, calcium chloride, and calcium nitrate, precipitate all native proteins, but not peptones. Magnesium sulphate precipitates all the less readily soluble proteins, but not those which are soluble in pure water. Common salt, sodium sulphate, acetate, and nitrate are even less effective, but they cause precipitation of caseinogen, fibrinogen, and some others.

This action is called flocculent precipitation or salting out. The proteins are not coagulated, or apparently changed in any way. The precipitates can be redissolved in water.

The process affords an important means of separating

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[1] *Chemie der Eiweisskörper.*

them from various impurities and from one another. It appears to be analogous to the salting out of soaps by brine, and is supposed to be due to partial dehydration or withdrawal of water from the protein by the salt. Other colloids exhibit the same property, and it is not improbable that many compounds of high molecular weight, *e.g.* carbohydrates, may also be capable of flocculent precipitation.

Crystallisation.—When a certain quantity of acetic acid is added to a solution of white of egg, half saturated with ammonium sulphate, the protein comes down as a bulky amorphous precipitate which on standing from six to twelve hours gradually assumes the crystalline form. It is uncertain whether these crystals consist of the simple proteins or salts (the acetate or sulphate) of the same.

Chemical Composition.—The exact chemical composition of the proteins is still a matter of some doubt owing to the difficulty of separating the compounds from each other, and from ash and other impurities. The composition of each particular compound is, doubtless, constant, but it is almost impossible to determine whether any given product represents a single pure compound. Also, the difference in the composition of some of the substances of widely different origin and different properties is often no greater than that obtained by different observers for one and the same substance. The following results, obtained in numerous analyses of serum albumin—a typical compound—may be taken as a practical average for the group.

	Per cent.
Carbon	53·08
Hydrogen	7·10
Oxygen	21·99
Nitrogen	15·93
Sulphur	1·90
	100·00

The composition of some of the compounds, however, differs considerably from the average. In general, they may contain from 52 to 54 per cent. of carbon, and from 15 to 19 per cent. of nitrogen. The percentage of sulphur varies within wider limits; keratin contains nearly 5 per cent. of that element, hæmoglobin only about 0·4 per cent.

In analyses of cattle foods, the "albuminoids" are usually estimated by multiplying the nitrogen by 6·25. This factor is based on the assumption that the compounds contain, on the average, 16 per cent. of nitrogen. [$100 \div 16 = 6{\cdot}25$.]

Molecular Weight.—The simplest formula for serum albumin, calculated from the percentage composition given above, is $C_{75}H_{120}N_{19}O_{23}S$. This corresponds to a molecular weight of 1686. It is tolerably certain, however, that the molecule contains more than one atom of sulphur; judging from the dissociation products, there are at least four, and some authorities hold that there are probably six, atoms of sulphur in the molecule. In the latter case, the formula would be $C_{450}H_{720}N_{114}O_{138}S_6$, and the molecular weight 10,116.

The molecular weight estimated by Raoult's method—the lowering of the freezing point of solvents—is 14,270; but this result is not considered reliable, and it cannot be checked from the boiling point of the solvents as the proteins coagulate. There is no room for doubt, however, that the molecular weight of all proteins—even of peptones which are among the simplest—must be very high.

Salts.—Of the proteins that are soluble in water, the great majority are neutral to litmus. Some, however, are alkaline and others are acidic. The latter displace carbon dioxide from carbonates. But whatever reaction they exhibit towards litmus, they all unite both with acids and with bases to form salt-like compounds.

It will be shown presently that the proteins are believed to be aggregates of amino-acids. It is probable that the acidic and basic radicles are present in equivalent proportions in the neutral proteins, but not in those which have an acid or alkaline reaction. The amphoteric character is common to all amino-acid bodies. Glycocine, for example, forms salts both with HCl and with NaOH (p. 50).

The sulphates, nitrates, and chlorides of the proteins are soluble to some extent in alcohol, and they are all more readily soluble in water than the original compounds. The potassium and sodium salts are also very soluble. They are of peculiar interest because such compounds occur in nature. Nucleo-albumin is an alkali-albuminate, and the caseinogen of milk is a calcium caseinate.

The acid and alkali salts of the proteins are easily saponified, *i.e.* the proteins are easily separated from the acid or base, by the action of water.

The albuminates of the heavy metals are all insoluble in water, and are, therefore, precipitated from aqueous solutions on addition of the salts of these elements. These reactions, it will be seen, are not at all analogous to the precipitation of the proteins by coagulating reagents.

Qualitative Tests.—The more important reactions which may be used as qualitative tests for the proteins fall naturally into two divisions, viz. (*a*) precipitation from solutions, and (*b*) colour reactions.

The former includes all those in which the proteins are precipitated—

(1) By reagents in which they are insoluble, *e.g.* alcohol, chloroform, etc. Flocculent precipitation by ammonium sulphate and other salts may be included under this head.

(2) In the form of a coagulum produced by heat or by the action of various reagents, *e.g.* phenol, acetone, etc.

(3) By salts of the heavy metals, *e.g.* mercuric chloride, basic acetate of lead, cupric sulphate, etc.

(4) By mineral acids, *e.g.* sulphuric, phosphoric, and nitric acids. The last is the most effective, but the precipitates are slightly soluble in excess.

(5) By alkaloid reagents, *e.g.* phosphotungstic acid, phosphomolybdic acid, tannic acid, ferrocyanic acid (potassium ferrocyanide and acetic acid), picric acid, potasso-mercuric iodide. The proteins resemble the alkaloids in many respects, and, like them, they form insoluble compounds with the reagents mentioned.

The colour reactions are, for the most part, not produced by the protein molecules as a whole, but by constituent radicles. Certain proteins do not give the colorations because the necessary radicles do not enter into their composition. On the other hand, the colours are produced by some non-protein substances which do contain these radicles. The colour reactions are not, therefore, very characteristic of the class. The more important are as follows:—

(1) *Biuret Reaction.*—A purple, violet, or, in some cases, a red colour on adding a drop of cupric sulphate and excess of caustic soda. This reaction depends on the formation of biuret, $NH(CO.NH_2)_2$.

(2) *Xanthoproteic Reaction.*—A yellow colour on heating with concentrated nitric acid; turns brown on addition of ammonia. Applicable to solids and liquids. Depends on the formation of nitrophenols.

(3) *Millon's Reaction.*—A pink colour, either in the cold or after heating, on adding acid mercurous nitrate; applicable to solids and liquids; positive results only with proteins which contain a benzene nucleus.

(4) *Vogel's Reaction.*—Lead acetate gives a white precipitate which turns black on boiling, owing to decomposition of the lead protein salt with formation of lead sulphide. Negative results with gelatine, peptones, and other proteins, which contain no sulphur.

(5) *The Molisch Reaction* (see p. 15).—This reaction is characteristic of the carbohydrates, and only those conjugated proteins which contain such radicles give positive results.

(6) *Adamkiewicz*[1] (*Hopkins and Cole's*) *Reaction.*—A red, green, or violet ring on adding concentrated sulphuric acid to a solution of the protein in glacial acetic acid. Positive results only with proteins which contain tryptophane.

(7) *Lieberman's*[1] *Reaction.*—A blue coloration on warming with fuming hydrochloric acid.

Dissociation.—When the acid and alkali salts of the proteins are "saponified" by the action of water (p. 68) the proteins undergo hydrolysis to a greater or less extent, and the properties of the products are not, therefore, exactly the same as those of the original substances. These products

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[1] For 6 and 7 the protein must be first purified from fat by treatment with ether.

were formerly called acid and alkali albumins respectively, but are now known as meta-proteins. By continued hydrolytic treatment, *e.g.* boiling with dilute acid or alkalis, the meta-proteins undergo further change and the products are described as proteoses and peptones. Similar changes are produced by ferments of various kinds, both organised and formless, *e.g.* bacteria, pepsin, etc.

Metaproteins, proteoses, and peptones are not distinct, well-defined classes of compounds, but merely transition products. They are to be regarded as recognisable stages in the gradual process of dissociation of the proteins. They readily undergo further hydrolysis and are transformed into polypeptides (p. 61) and finally into amino-acids. Provided the acid is not too strong and the action is not unduly prolonged, the amino-acids are obtained with the carbon chains apparently intact and the nitrogen atoms in their original positions. They are called primary dissociation products to distinguish them from the products of further change in which the amino-acids are split up or altered. The latter are called secondary dissociation products.

Glycocine, alanine, serine, leucine, asparagine, arginine, histidine, cystine, tyrosine, and tryptophane (p. 52) are amongst the most important of the primary dissociation products, but there are many others. The kinds and quantities of the primary dissociation products are characteristic of the type of protein from which they are obtained.

It is to be supposed, therefore: (1) that the proteins are complex aggregates of the radicles of these compounds; (2) that the nature of the union is similar to that of the polypeptides. In short, it appears that the proteins are merely complex polypeptides, and that the properties of the individual compounds depend upon (*a*) the particular amino-acids which enter into their composition, and (*b*) the relative proportions in which they are present.

The process by which one kind of protein is converted into another—as, for instance, in the formation of animal tissues from vegetable foods—appears to consist in the resolution of the protein into primary dissociation products which are then selected and re-elaborated in a different proportion ; any group or portion which does not enter into the composition of the new compound is simply split off and rejected.

Meta-proteins, Proteoses, and Peptones.—These products always resemble the parent protein more or less closely in composition and general properties. They differ from it, and from each other chiefly in regard to those physical properties of colloids which depend on molecular complexity, *e.g.* solubility, diffusibility, etc.

The proteoses are not coagulated by heat, but they are precipitated by alcohol, and are floculated by ammonium sulphate. They react with mercuric chloride and salts of other heavy metals, forming insoluble albuminates, are precipitated by ferrocyanic acid and other alkaloid reagents, and they give the biuret and xantho-proteic reactions. They are distinguished as primary and secondary proteoses according as they resemble more closely the parent protein or the peptone into which they are ultimately transformed. The distinction between the secondary proteoses and the peptones is, in some cases, purely arbitrary. Those which are precipitated by cupric salts are classed as primary proteoses, and those which are not, as secondary. This reaction may be used as a means of separating the former from the latter.

The various kinds of proteose are distinguished as albumose, globulose, caseose, etc., according to the type (p. 72) of protein from which they are derived.

Peptones contain no sulphur. They are not coagulated by heat, and are not salted out by ammonium sulphate. They are not precipitated by alcohol, and do not form insoluble albuminates with salts of heavy metals. They are, however, precipitated by some of the alkaloid reagents, and they give the biuret and xantho proteic reactions. The peptones are simpler than the proteoses, *i.e.* they have a lower molecular weight, and they are more soluble and diffuse more rapidly.

When proteins are peptonised, it is always found that one part is more resistant to the action of the ferment than the other. The former yields glycocine, phenylalanine, and pyrrolidine-carboxyllic acid. The latter contains tyrosine and tryptophane. For example, trypsin rapidly converts native proteins into leucine, tyrosine, etc., and a remainder which gives the biuret reaction (*i.e.* it is a peptone), when all the tyrosine is removed. This remainder has been called anti-peptone, and the less resistant part is called hemi-peptone. The original protein, therefore, appears to be composed of two groups of radicles which are known as the hemi-group and the anti-group respectively.

Classification.—The original method of classifying proteins according to their origin and solubility, is at once arbitrary and unsatisfactory, and has been the cause of much confusion. In recent years it has been modified by taking into consideration the composition and properties of the compounds; but sufficient data are not yet available to allow of this—the only scientific method—being made the primary basis of classification. The following scheme was adopted by the Chemical and Physiological Societies in 1907, but it must be regarded as tentative and incomplete.

CLASSIFICATION OF PROTEINS.

- Native proteins
  - Simple
    - Albumins.
    - Globulins.
    - Phospbo-proteins.
    - Glutelins.
    - Gliadins.
    - Histones.
    - Protamines.
    - Sclero-proteins.
  - Conjugated
    - Nucleo-proteins.
    - Gluco-proteins.
    - Chromo-proteins.
- Derivatives
  - Meta-proteins
    - Acid albumins.
    - Alkali albumins.
  - Proteoses
    - Albumoses, etc.
  - Peptones
  - Polypeptides
  - Amino-acids

The terminology employed in this classification is not entirely satisfactory. The proteoses and peptones are, no doubt, derived from other proteins, but they might well be regarded as native, inasmuch as they occur in nature. The polypeptides and amino-acids are also derived from proteins by natural as well as by artificial processes, but they are not generally regarded as members of the protein class.

Albumins and Globulins.—These occur together in most of the tissues and fluids of both animals and plants. Albumins appear to be converted into globulins on prolonged dialysis of their solutions at temperatures between 75° and 85° C. Certainly they are very much alike. They differ chiefly in regard to solubility.

The albumins are soluble in pure distilled water, and are not floculated when the solutions are saturated with common salt or magnesium sulphate. The globulins are insoluble in pure water and in dilute acids; but they are soluble in dilute alkalis and in solutions of neutral salts. They are more easily coagulated by heat than the albumins, and more readily floculated by ammonium sulphate. They are completely precipitated when their solutions are saturated with magnesium sulphate and partially even by common salt. When pure, the globulins have a faintly acid reaction.

Particular specimens are generally named after the source from which they are derived, *e.g.* serum albumin and serum globulin from the serum of blood and lymph, lactalbumin and lacto-globulin from milk, ovalbumin and ovoglobulin from eggs, and so on. Fibrinogen and myosinogen and their derivatives, fibrin and myosin, also most of the vegetable proteins, *e.g.* edestin of hempseed, legumin of peas, and conglutin of lupines, are all classed as globulins. Vegetable albumins occur in cabbage and other plants.

The fibrinogen of blood on exposure to air is rapidly dissociated into fibrin and another protein called "fibrin globulin." The former appears as a voluminous curdled mass, while the latter remains in solution. The clotting of blood is due to this change. It is caused by the action of a ferment which is normally present in the blood. The change is not of the nature of coagulation—both of the products can be coagulated—and it is independent of the presence of calcium salts.

Glutelins and Gliadins.—The elastic, glue-like mass which gives the toughness or " strength " to dough, and which can be obtained from wheat flour by removal of the starch, was formerly called gluten. When separated from adventitious impurities, *e.g.* starch, fat, etc., this substance is found to consist of a mixture of proteins of which the most important are now called glutelin and gliadin, or wheat-glutelin and wheat-gliadin to distinguish them from similar compounds in other cereals. The gliadins are insoluble in water, but are soluble in alcohol of 70 to 80 per cent. strength. The glutelins are insoluble in water and in alcohol, but are very readily soluble in dilute acids and alkalis. The gliadin of oats has been called avenin; that of maize, zein; that of barley, hordein, and so on.

Phospho-proteins.—As the name implies, the members of this group contain atoms of phosphorus in the molecule, and they exhibit a marked acid reaction. They are insoluble in water, but readily form salts with alkalis and ammonia which are soluble in water and are not coagulated on boiling. Being insoluble, the phospho-proteins are precipitated from solutions of their salts on addition of acids. If the quantity of acid is just sufficient to acidify the solution, but not enough to cause precipitation, the phospho-protein coagulates on warming.

Three stages can be recognised in the reaction which takes place when phospho-proteins are treated with pepsin in the presence of hydrochloric acid. First, the protein is dissolved and partially converted into proteose. Second, a radicle containing phosphorus is split off. Third, the phosphorus containing radicle is dissolved while the peptonisation of the remainder proceeds. The portion which contains the phosphorus has a marked acid character, and is readily soluble in alkalis. It has unfortunately been called "paranucleic acid," but it has no connection with nuclein (p. 79). The paranucleic acid is precipitated from its alkali solutions by acids. It readily dissociates into acid albumin, albumose, and phosphoric acid.

Casein, the chief nitrogenous constituent of milk, is a phospho-protein. It is obtained as a curdy precipitate when acids are added to milk from which the fat has been previously separated. To purify it, the precipitate must be dissolved in alkali and reprecipitated several times, and then extracted with alcohol and ether. Though itself an acid, it can, like other proteins, form salts with acids. These are soluble in water, and the casein precipitated by acids is therefore soluble in excess.

The potassium, sodium, and ammonium salts of casein are also soluble. The clear solutions pass through clay filters, and are not precipitated by charcoal or other porous substances. In these salts it has an equivalent weight of 1135, and the acid is at least tetrabasic, probably hexa-basic. The commercial product known as "Eucasein" is the ammonium salt. "Nutrose" and "plasmon" are sodium and potassium caseinates.

The caseinates of calcium and other earths form opalescent solutions, from which the protein is precipitated by charcoal and other finely divided insoluble substances. These solutions cannot, therefore, pass through clay filters.

In milk, the casein is present in the form of a calcium salt (calcium dicaseinate), in intimate association with calcium phosphate—probably as a true double salt. When casein is precipitated, the calcium phosphate is also thrown down. The term "casein" is often loosely applied to this complex product which occurs in milk, and also to the coagulum produced by the action of rennet. It should, however, be reserved strictly for the free acid, *i.e.* the phospho-protein, pure and simple. The term "caseinogen" is now generally used to distinguish the original substance, *i.e.* calcium caseinate, which occurs in milk.

It is difficult to say with certainty whether this caseinogen is in true solution or, as Fleischmann has it, merely suspended in a bulky colloidal condition. As a calcium salt it is not coagulated by heat even on boiling. The so-called "haptogen membrane"—the scum which forms on the surface when milk is warmed—is produced by coagulation of the albumin and globulin. It contains fat and other substances mechanically associated. It is probable, however, that the caseinogen does undergo change when milk is boiled. Solutions of pure calcium caseinate become turbid on warming to about 35° C., owing to a partial hydrolytic separation of the base. The turbidity disappears again on cooling, probably owing to reformation of the original salt. These changes may be roughly indicated by an equation as follows :—

$$\text{Ca-caseinate} + 2H_2O \rightleftarrows Ca(OH)_2 + \text{casein}$$

By the action of the rennet ferment, casein is converted into a soluble form called para-casein. This substance reacts with calcium salts, forming calcium para-caseinate, which is insoluble, and is therefore precipitated as a curd. If all the calcium salts be first removed from solution by precipitation with ammonium oxalate, the first stage of the change, *i.e.* the conversion of casein into soluble para-casein, takes place, but the second does not, and the curd is not formed.

Vitellin, the chief protein in the yolk of birds' eggs, and ichthulin, obtained from the ova of fish, both belong to the phospho-protein group.

Histones and Protamines.—These exhibit a strongly basic character, owing to the preponderance of basic radicles in the molecule. They are precipitated from aqueous solutions by alkalis, and even by ammonia, but are soluble in excess.

The histones are coagulated by heat only in the presence of salts. They are precipitated by the alkaloid reagents from neutral solutions, whereas other proteins react only in the presence of acids. The percentage of sulphur in histones is smaller, and that of the nitrogen larger, than in the typical compounds. Histones can unite with serum-albumin, ovalbumin, and with casein, and the compounds come down as precipitates when these substances are added to neutral solutions. Globin, the essential protein radicle of hæmoglobin, is a histone.

Protamines are even more strongly basic than histones. They are precipitated by alkaloid reagents, even from alkaline solutions, and are not coagulated by heat. Protamines contain no sulphur at all, and they contain less carbon than the typical compounds. The percentage of nitrogen is higher, owing to the preponderance of arginin in their composition. The last-mentioned substance forms from 50 to 80 per cent. of the primary dissociation products of the protamines.

Sclero-proteins.—Until comparatively recent times it was considered doubtful whether these substances should be regarded as true proteins or merely as allied bodies. The term "albuminoids" was exclusively applied to them by some authors to emphasise this difference. They occur chiefly in the external coverings, supporting structures and fibrous tissues of animal bodies, *e.g.* skin, hair, cartilage, bones, tendons, etc. In the native condition they are all very hard or tough, and insoluble. They are, therefore, more difficult to investigate than the more readily soluble compounds previously considered. It has been found, however, that they give the same colour reactions, form similar salts with acids and bases, are resolved by ferments and by hydrolytic treatment into proteoses, peptones, and, finally, into amino-acids. In short, the differences between the sclero-proteins and the other members of the group are mainly superficial.

Collagen and keratin are amongst the most important sclero-proteins; and these differ so widely in point of composition and properties that it is doubtful whether they should really be included in the same group. For example, the former contains no sulphur, whereas the latter contains about 5 per cent. of that ingredient.

Collagen is the name given to the substance which forms the ground matrix of bones, cartilage, and fibrous tissues (tendons, etc.). It can be obtained by exposing these to tryptic digestion, by which the other albuminoids are rendered soluble; the collagen is left unchanged. On prolonged boiling with water, or more rapidly in the presence of acids, it undergoes a change—probably a process of hydration—and is converted into gelatine, sometimes called glutin, or, in its impure state, glue.

Gelatine is soluble in hot water, but insoluble in cold, and solutions containing more than about one per cent. of the substance set as a jelly on cooling to ordinary temperatures. The commercial product is usually obtained in the form of thin, yellowish, transparent plates. These contain from 10 to 15 per cent. of water. The pure, anhydrous substance is a colourless, amorphous powder. It varies slightly in composition, but the average of numerous analyses is as follows: carbon, 50; hydrogen, 7; nitrogen, 18; oxygen, 25 per cent. Sulphur is absent or present only in traces, probably as impurity.

Under hydrolytic treatment with acids, or by the action of ferments, gelatine is converted first into a proteose, and subsequently into peptone. Tyrosine and tryptophane are not present, and the xanthoproteic and Millon's reaction consequently give negative results. Gelatine gives a well-marked biuret colour, but, owing to the absence of sulphur, it does not give Vogel's reaction. It is not precipitated by acids or by normal salts of lead or copper, but mercuric chloride, basic acetate of lead, and most of the alkaloid reagents produce precipitates. It is insoluble in alcohol, and is thrown down by that reagent and by tannic acid from salt-free solutions.

Keratin is the chief constituent of horn, hoofs, hair, wool, feathers, etc. It is quite insoluble in water, and is strongly resistant to the action of acids, alkalis, and digestive ferments. Dilute (10 per cent.) acids and alkalis have no effect upon it in the cold. Stronger solutions decompose it. Keratin is therefore easily prepared from the substances mentioned. Fat and other adventitious matters are removed by extraction with alcohol and ether, and the residue is then boiled successively with dilute acids and alkalis, which hydrolyse all other proteins.

Analyses of keratin from various sources differ considerably, but they all show a large amount of sulphur—usually about 5 per cent. The dissociation products include exceptionally large amounts of cystin and tyrosine, and the substance gives very strong colorations with the xanthoproteic, Millon's and Vogel's reactions. Proteoses and peptones have been formed by the action of superheated steam on keratin.

Conjugated Proteins.—The conjugated proteins may be regarded as analogous to the compound celluloses (p. 29).

They are homogeneous chemical compounds of true proteins, with a non-protein radicle called the prosthetic group. They are classified as nucleo-proteins, chromo-proteins, and gluco-proteins, according as the prosthetic group is a nucleic acid, a chromogenic substance, or a carbohydrate.

The nucleic acids, of which there are probably several, contain phosphorus and nitrogen, but no sulphur, in the molecule. The phospho-proteins previously described, *e.g.* casein, contain no nucleic acid—they are simple proteins—and should not be confused with the nucleo-proteins. The dissociation products of nucleic acid are very complex. They include phosphoric acid, pyrimidine and purine derivatives, pentoses, and lævulinic acid. The probable composition of the nucleic acids is represented by the empirical formula, $C_{40}H_{54}N_{14}O_{27}P_4$. They are readily soluble in hot water and in alkalis. They are precipitated from solution by dilute acids, but are soluble in excess. Alcohol, salts of heavy metals, and the alkaloid reagents, also precipitate the nucleic acids.

Nucleic acids are never split off directly from the nucleo-proteins. On dissociation these substances are resolved first into histone and nuclein. The latter is an albumin-nucleate, and splits up into albumin and nucleic acid on further resolution. This may be expressed, graphically, as follows :—

$$\text{Nucleo-protein}\begin{cases}\text{Simple protein—Histone}\\ \text{Nuclein}\begin{cases}\text{Albumin}\\ \text{Nucleic acid}\end{cases}\end{cases}$$

Nucleo-proteins were so called because they enter largely into the composition of the cell nuclei. They are, therefore, obtained from those tissues of plants and animals which have a cellular structure. They are all markedly acid, are soluble in water and salt solution, and more readily in alkalis. They are precipitated by acids, but are soluble in excess. They are coagulated by heat and by various reagents like the simple proteins, but the nucleic acid takes no part in the change, and may be separated from the coagulum. Nucleo-proteins give the same precipitation and colour reactions as the simple compounds, and they give much the same dissociation products plus those that are derived from the nucleic acid radicle.

Hæmoglobin, the substance of which the red corpuscles of blood are mainly composed, is perhaps the most important example of the chromo-proteins. In this case the chromogenic substance is a compound of iron, but little is known regarding the way in which the iron is combined with the other atoms in the molecule, except that it is non-ionic.

Hæmoglobin has the peculiar property of forming compounds with oxygen and with carbon-monoxide. The oxygen compound is formed in the normal course of animal respiration, *i.e.* when the blood is exposed to the action of air in the lungs. It is in this way that oxygen is carried to all the tissues of the body to which the hæmoglobin readily yields it up. The deoxidised hæmoglobin again returns to the lungs, and the process is repeated continuously during life. The carbon-monoxide compound is more stable, and animals inhaling air contaminated with that gas are gradually asphyxiated, as the process of oxidation is thus arrested. Both compounds are of a bright red colour, whereas the deoxidised hæmoglobin is bluish. In normal circumstances, therefore, the arterial blood of animals is red and the venus blood is blue; but in animals which have been poisoned with carbon-monoxide gas, both the arterial and the venus blood are red. An analogous compound called hæmocyanin, in which the iron of hæmoglobin is replaced by copper, has been found in the blood of crayfish and other cephalopods in which it apparently performs similar functions.

Apart from their physiological importance, the compounds of hæmoglobin with oxygen and with carbon-monoxide are of considerable interest from another point of view. From the proportion in which it unites with these substances, it is possible to determine the molecular weight of hæmoglobin, and the result corresponds closely with that calculated from the percentage composition on the assumption that the molecule contains only one atom of iron. According to this datum the simplest formula for hæmoglobin is $C_{758}H_{1203}N_{195}O_{218}FeS_3$, which corresponds to a molecular weight of 16,669. This conclusion is the more important because hæmoglobin is easily crystallised, and so can be obtained in a pure state for experiment; but it affords no information regarding the molecular weight of globin as it is not known whether one or several molecules of the latter are united with hæmatin, the chromogenic radicle.

The gluco-proteins contain no phosphorus, and they are much more stable than the nucleo-proteins. The prosthetic (carbohydrate) group can be dissociated from the protein only by prolonged boiling with mineral acids or alkalis. As a consequence of this drastic treatment, the proteins are resolved to proteoses—or even to amino-acids—and the carbohydrate is obtained as glucosamine, $C_6H_{11}O_5NH_2$. It is impossible, therefore, to tell in what form these two products were originally present in the gluco-protein molecule; but it is highly probable that both result from the disintegration of radicles of much greater complexity.

The gluco-proteins are represented chiefly by the mucins and mucoids, which occur in the slimy fluids found on the surfaces of all mucous membranes, *e.g.* those of the intestines. These fluids serve as lubricants, and it is the gluco-proteins which impart the slimy character to them.

Quantitative Determination of Protein.—Kjeldahl's method is now generally employed for the quantitative determination of nitrogen in organic matter, *e.g.* feeding stuffs. In this process, the substance is boiled with concentrated sulphuric acid until the carbon is completely oxidised and the nitrogen is converted into ammonia which remains in combination with the acid. Excess of alkali is then added to liberate the ammonia which is distilled off, and the amount of standard acid which it neutralises is determined by titration in the usual way. The nitorgen multiplied by the factor 6·25 (p. 67) gives the total nitrogenous matter or crude protein.

In practically all feeding stuffs, except those composed of seeds, *e.g.* oil cake, it is necessary to discriminate between the true protein and the so-called amides (amino-acids, etc.). To do this, the substance is treated with a hot 4 per cent. solution of phenol—aqueous or alcoholic—to which a small amount of meta-phosphoric acid has been added. The soluble nitrogenous compounds (amides) which are not coagulated by this treatment are then filtered off. The residue which contains the true, coagulated proteins, is well washed with the precipitating reagent to complete the separation, and the nitrogen is determined in it as before. In Stutzer's method, the soluble proteins are precipitated by warming with moist cupric hydrate instead of being coagulated with phenol; but in other respects it is the same in principle as that described above.

The nitrogen in the coagulated residue multiplied by the factor 6·25 gives the true protein. The difference between this and the total nitrogenous matter or crude protein is often rendered in analytical reports as amides. The value so obtained, it will be seen, does not correspond to any particular compound; it is merely the non-protein or amidic nitrogen multiplied by 6·25. Sometimes this non-albuminoid nitrogen is calculated as asparagine or other typical amide. Vegetable matter, particularly roots, often contains a certain amount of nitrogen as nitrates, which, of course, must be determined separately.

For further information see "Chemistry of Proteides" by Mann.

CHAPTER VII

FERMENTS AND MISCELLANEOUS PRODUCTS

Ferments.—Frequent reference has been made in previous chapters to the action of ferments. It may be well to explain briefly what these are and how they act.

The ferments with which we are here chiefly concerned are those known as enzymes. They are complex, nitrogenous substances of uncertain composition, but they are believed to be homogeneous compounds of an albuminous nature. They are present in seeds and starchy vegetables, and in the gastric juice and other digestive fluids of animals. They cause various chemical changes, which take place in the processes of germination, translocation, and digestion. These changes are known generally as fermentations.

The term "fermentation" is derived from the French *fervere*, "to boil." It was originally applied to the changes produced by organisms like yeast, which, when added to brewers' worts, transform the sugars into alcohol and carbonic acid gas. The frothing due to the evolution of the gas produces the appearance of boiling. The term is now applied not only to similar changes produced by other organisms—even those in which gases are not evolved—but also, as indicated above, to those due to the action of enzymes.

There is reason to believe that all fermentations are due ultimately to the action of enzymes, and not, as was formerly supposed, directly to the vital activity of the organisms. It is known, for instance, that the chemical changes which are incidental to the growth of yeast in sugar solutions can be brought about by the juices extracted by pressure from the organism when the cells are thoroughly disintegrated. The same is true also of other cases, and, as has been said, possibly in all; but there are many fermentations which have not, so far, been observed to occur except in the presence of living organisms.

In some fermentations the changes take place outside the cells, and in others within it. In the former case, the enzyme produced by the organism is probably excreted into the fermenting liquid. In the latter, the fermentable substance is probably absorbed into the cells of the organism, and the substances produced by the action of the enzyme in the cell are excreted into the liquid.

Enzymes such as diastase, pepsin, etc., are sometimes called unorganised or formless ferments, in contradistinction to the organised or living ferments such as yeast, bacteria, etc., which, of course, are cellular plants.

It is difficult to understand the part played by the organisms in those changes which are apparently due to their direct action, even when the chemical nature of the change is known. Fermentations due to the action of enzymes we may hope ultimately to unravel, however obscure and complex they may be, as they are probably ordinary chemical reactions resulting from the action of the enzymes on the fermented substances. It is characteristic of these changes that the ferments themselves remain apparently unaltered, and relatively small amounts can therefore cause the transformation of practically unlimited quantities of the substance.

Many similar or analogous reactions are familiar to all students of chemistry, *e.g.* the oxidation of sulphur dioxide by oxides of nitrogen, which act as carriers, the etherification of alcohol, various catalytic reactions, and the hydrolysis of bihexose sugars and amyloses (pp. 21, 26) by dilute acids. The last is peculiarly apposite, because the same result, produced by the action of enzymes, is often regarded as a typical fermentation.

In the process of etherification, the sulphuric acid combines with the alcohol, and, by a secondary reaction, it is again regenerated according to the equations—

$$(1)\ C_2H_5OH + H_2SO_4 \rightarrow C_2H_5HSO_4 + H_2O$$
$$(2)\ C_2H_5HSO_4 + C_2H_5OH \rightarrow (C_2H_5)_2O + H_2SO_4$$

and the process can go on indefinitely. In the hydrolysis of starch and sugars there is reason to believe that the substances combine with the acid, forming esters or similar compounds, which are rapidly saponified by the water with the regeneration of the acid.

It is considered highly probable that the hydrolytic action of enzymes takes place in a similar manner, *i.e.* that the enzyme combines with the substance, and that the compounds are subsequently resolved with the liberation of the ferment in its original form. Indeed, it is claimed that compounds of certain proteolytic enzymes with proteins have been isolated, and that on digesting them with water at certain temperatures, these compounds are resolved into peptones and the original ferments.

The products of fermentative changes are generally less complex, *i.e.* they are of lower molecular weight, and contain less potential energy than the original compounds. The comparatively few instances in which the reverse occurs cannot be traced to the action of enzymes, and it is doubtful if they should be regarded, strictly, as fermentations. The more complex compounds produced are generally constituents of the organism itself, and the energy required for their formation is probably derived from the oxidation or alteration of some other compound or part of the compound, which is transformed.

The simpler fermentations may be generally referred to one or other of the following types of chemical change :—

(1) Decomposition of a molecule into two or more simpler molecules of the same or of different kinds, *e.g.* the conversion of sugars into alcohol and carbon dioxide.

$$C_6H_{12}O_6 \rightarrow 2C_2H_5OH + 2CO_2$$

(2) Hydrolysis or simple decompositions in which the products combine with the elements of water, *e.g.* the inversion of cane sugar.

$$C_{12}H_{22}O_{11} + H_2O \rightarrow C_6H_{12}O_6 + C_6H_{12}O_6$$

The diastatic fermentation of starch, decomposition of glucosides (p. 87), saponification of fats, and the peptonisation of proteins, all belong to this type.

(3) Oxidation, *e.g.* the conversion of alcohol into acetic acid.

$$C_2H_5OH + O_2 \rightarrow C_2H_4O_2 + H_2O$$

(4) Reduction: changes which result in the formation of hydrogen and substances containing a smaller proportion of oxygen than the original compounds, *e.g.* formation of butyric acid, etc., from lactic acid.

$$2C_3H_6O_3 \rightarrow C_4H_8O_2 + 2CO_2 + 2H_2$$

In addition to the compounds formed by the main reaction, others are also produced by secondary changes, or by changes of a different kind, which take place simultaneously in nearly all fermentations. What actually occurs, therefore, cannot, as a rule, be represented by a single chemical equation. Many fermentations are extremely complex, and probably involve several changes of different types at once, *e.g.* oxidation or reduction together with hydrolysis and simple decompositions, each of which may proceed in many different directions. The transformations known generally under the name of putrefaction, those which take place during the ripening of cheese, and possibly also certain stages in the processes of digestion, are of such a complex character. When the changes occur under carefully regulated conditions, the results are of a more or less specific character, but the products are not constant either qualitatively or quantitatively.

The decomposition of cellulose, which takes place under the anaerobic conditions prevailing in marshy soils, is probably a very complex process; but, as methane and free hydrogen are amongst the products, it may be regarded as mainly a process of reduction. Changes of a somewhat similar character appear to take place during the digestion of cellulose by herbivorous animals. The process has been artificially imitated by inoculating nutritive matter with the contents of different portions of the alimentary tract. Two different types of fermentation were observed, characterised by preponderance of hydrogen and of methane respectively. Upwards of 50 per cent. of the total cellulose disappeared, and the composition of the gases evolved was as follows :—

	I. (Per cent. by volume.)	II. (Per cent. by volume.)
Carbon dioxide and sulphuretted hydrogen .	84·5	55·4
Hydrogen (free) . . .	0·3	42·7
Nitrogen	2·7	1·9
Methane	12·5	—
	100·0	100·0

In both cases it is believed that the changes were due to the action of micro-organisms, but these were not isolated. It is now known that only a small proportion of the cellulose which disappears in the process of digestion goes in this way (p. 32), and that the larger part of the digestible cellulose is converted into sugar and absorbed.

Only a few of the ferments have been actually isolated. Those which were first discovered were given various empirical names, *e.g.* pepsin, trypsin, ptyalin, diastase. The great majority are known only through their action. In recent years there has been an attempt to classify them accordingly. The types to which they are referred are generally named with the termination *-ase*, from diast*ase*, but many of the older established names still prevail. An enzyme which hydrolyses malt sugar is called a maltase, one which acts on starch an amylase, on urea a urease, on casein a casease, and so on. The ferment diastase belongs to the amylase type, those which resolve cellulose into sugars belong to the cytase type, and those which saponify fats to the lipase type.

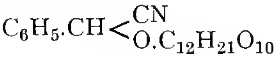
Glucosides.—Glucosides may be defined as vegetable products which are resolved into hexose sugars, chiefly glucose, and other compounds—acids, aldehydes, etc.—by the action of enzymes. A few yield pentoses instead of hexoses, and are sometimes classified as a sub-group, under the name of pentosides. The enzymes which cause the hydrolysis are usually associated with the glucosides in the plants in which they occur; and the change, therefore, takes place "spontaneously" when the substances are macerated with water.

It is evident from the reactions which define the class that the glucosides are to be regarded as esters of glucose or other sugars, and as several of the simpler compounds have been prepared synthetically, there is no room for doubt that this view is exact. Several members of the group contain nitrogen, but the majority are composed of carbon, hydrogen, and oxygen only. As many glucosides are met with in other connections, it will be sufficient for the present to mention one or two typical examples.

Amygdalin, $C_{20}H_{27}O_{11}N$, occurs in bitter almonds, the leaves of the cherry laurel, and in various parts of other plants, but especially in kernels, *e.g.* of apricots, peaches, cherries. It is soluble in water and in hot alcohol, and crystallises from the latter on cooling. When bitter almonds are macerated with water, the amygdalin dissolves, and the enzyme, called emulsin, which is also present, effects the hydrolysis of the compound. A similar change can also be brought about by the action of dilute acids. The products are the same in both cases, viz. glucose, hydrocyanic acid, and benzaldehyde (oil of bitter almonds).

$$\underset{\text{(Amygdalin.)}}{C_{20}H_{27}O_{11}N} + 2H_2O \rightarrow \underset{\text{(Glucose)}}{2C_6H_{12}O_6} + \underset{\text{(Benzaldehyde.)}}{C_6H_5CHO} + HCN$$

The probable constitution of the compound, therefore, is indicated by the formula—



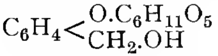
$$C_6H_5.CH<\begin{matrix}CN\\O.C_{12}H_{21}O_{10}\end{matrix}$$

The bihexose compound is resolved into glucose when it is split off. Alkalis produce a similar effect, but, of course, the nitrogen is evolved as ammonia.

Salicin, $C_{13}H_{18}O_7$, occurs chiefly in the leaves and young bark of willows, but is found also in certain species of poplar and other plants. It is extracted with boiling water and can be easily crystallised. It has an extremely bitter taste, but is quite neutral to litmus. By the action of ferments or of dilute acids it is resolved into glucose and saliginin (*O.* oxybenzyl alcohol).

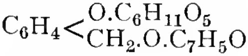
$$\underset{\text{(Salicin.)}}{C_{13}H_{18}O_7} + H_2O \rightarrow \underset{\text{(Glucose.)}}{C_6H_{12}O_6} + \underset{\text{(Saliginin.)}}{C_6H_4(OH)CH_2OH}$$

It has been prepared synthetically, and its constitution and that of other glucosides of saliginin are given as follows :—



$$C_6H_4{<}\begin{matrix}O.C_6H_{11}O_5\\CH_2.OH\end{matrix}$$

(Salicin.)



$$C_6H_4{<}\begin{matrix}O.C_6H_{11}O_5\\CH_2.O.C_7H_5O\end{matrix}$$

(Populin.)

$$C_6H_4{<}\begin{matrix}O.C_6H_{11}O_5\\CHO\end{matrix}$$

(Helicin.)

Arbutin, on hydrolysis, yields glucose and hydroquinone (dihydroxybenzene).

$$\underset{\text{(Arbutin.)}}{C_{12}H_{16}O_7} + H_2O \rightarrow \underset{\text{(Glucose.)}}{C_6H_{12}O_6} + \underset{\text{(Hydroquinone.)}}{C_6H_4(OH)_2}$$

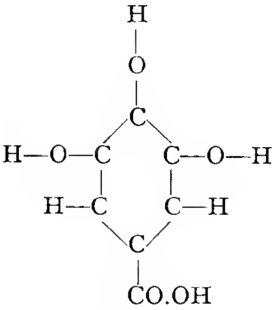
Potassium myronate, which occurs in the seeds of both the black and white mustard, is resolved by acids and by ferments into potassium hydrogen sulphate, glucose and mustard oil (allylisothiocyanate).

$$\underset{\text{(Pot. myronate.)}}{C_{10}H_{18}NS_2O_{10}K} \rightarrow \underset{\text{(Glucose.)}}{C_6H_{12}O_6} + \underset{\text{(Mustard oil.)}}{C_3H_5NCS} + KHSO_4$$

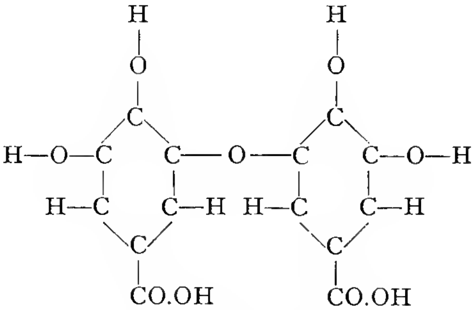
Tannins.—The name "tannin" was originally given to the compound found in the aqueous extract of oak bark which is used in the process of tanning hides. It has since been extended to a large number of substances of a more or less similar character which are widely distributed in the vegetable kingdom. They occur in quinine bark, tea leaves, coffee beans, beech nuts, etc. These are called physiological tannins in contradistinction to the pathological product found in oak galls to the extent of 50 per cent.

The tannins are all soluble in water and have a bitter, astringent taste. They give a very dark blue or green coloration (ink) with ferric salts, and are precipitated by neutral solutions of lead acetate. They precipitate the soluble proteins, including gelatine (pp. 65, 78), and are used chiefly for this purpose in the process of converting hides into leather. The tannin of coffee beans is an exception to this rule.

The tannins are all derivatives of gallic acid, a trihydroxy benzoic acid. Some of them occur as glucosides, *i.e.* as glucose esters of gallic acid. In others the glucose is replaced by trihydroxy benzenes, $C_6H_3(OH)_3$, pyrogallol [1, 2, 3], phloroglucin [1, 3, 5], etc. The common tannin, or tannic acid, is a digallic acid, and it occurs in oak galls in that form, not as a glucoside or other compound of the acid. The relation of this substance to gallic acid will be readily understood from the formulæ.



(Gallic acid.)



(Digallic acid (Tannin).)

The constitution of the other tannins can be indicated in a similar way, by replacing one of the gallic acid radicles by the phloroglucin or glucose radicle.

Colouring Matters.—Colouring matters of various kinds are of common occurrence in the organic world, both animal and vegetable. To the former belong the characteristic colours of blood, bile, yolk of egg, etc.; to the latter, chlorophyll, indigo, alizarin. Some of the vegetable colours are used as dyes, but they have been largely superseded by aniline colours derived from coal tar. Even those which have continued in use are now, to a large extent, manufactured by chemical processes.

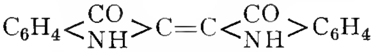
They are all composed mainly of carbon, hydrogen, and oxygen, but several contain also nitrogen. Though very complex, a number of the vegetable colours have been synthetically prepared, and their constitution is well understood. Many of them occur in plants as glucosides, and are obtained on hydrolysis of these compounds. Some are acids, and others have not yet been investigated.

Indigo, the blue colouring matter obtained from the twigs and leaves of several species of plants, occurs in the form of a glucoside called indican. This compound is resolved by the action of ferments, or of dilute acids, into glucose and indoxyl; the latter is a colourless body, but on oxidation yields indigotin (indigo blue).

$$\underset{\text{(Indican.)}}{C_{14}H_{17}O_6N} + H_2O \rightarrow \underset{\text{(Indoxyl.)}}{C_8H_7ON} + \underset{\text{(Glucose.)}}{C_6H_{12}O_6}$$

$$2C_8H_7ON + O_2 \rightarrow 2H_2O + C_{16}H_{10}O_2N_2$$

A number of other products of brown and red colours are obtained at the same time, and are separated by solvents. The indigotin, $C_{16}H_{10}O_2N_2$, is then purified by sublimation. The constitution indicated by the formula below is ascribed to it.



$$C_6H_4 < \begin{matrix} CO \\ NH \end{matrix} > C = C < \begin{matrix} CO \\ NH \end{matrix} > C_6H_4$$

(Indigotin.)

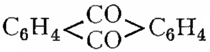
It is insoluble in water, alcohol, and dilute acids, but dissolves readily in strong sulphuric acid and some organic solvents.

A substance similar to indican sometimes occurs in the urine of herbivora, and gives rise to a blue coloration when the liquid is allowed to stand, or is treated with dilute acids.

Alizarin, another important vegetable dyestuff, is obtained from the roots of madder. It occurs in the form of a glucoside called ruberythric acid. The latter is easily resolved by the action of acids, or by certain ferments, into alizarin and glucose.

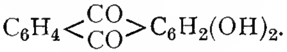
$$C_{26}H_{28}O_{14} + 2H_2O \rightarrow C_{14}H_8O_4 + 2C_6H_{12}O_6$$

Alizarin, it has been ascertained, is dihydroxyanthraquinone. The constitution is shown below.



$$C_6H_4\left<\begin{matrix}CO\\CO\end{matrix}\right>C_6H_4$$

(Anthraquinone.)



$$C_6H_4\left<\begin{matrix}CO\\CO\end{matrix}\right>C_6H_2(OH)_2.$$

(Alizarin.)

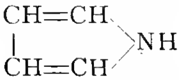
Another dyestuff called purpurin is also obtained from madder roots. It is the trihydroxyanthraquinone, $C_{14}H_8O_5$.

The bile contains several pigments known as bilirubin, biliverdin, bilifuschin, etc. They appear to be related to the red colouring matter of the blood hæmoglobin (p. 80) or hæmatin, and are probably formed from it, but they contain no iron. The formula $C_{32}H_{36}N_4O_6$ is ascribed to bilirubin. The substance is of a reddish-yellow colour, insoluble in water, but soluble in alcohol and other organic solvents. Alkaline solutions, when exposed to air, absorb oxygen, and are converted into biliverdin, $C_{32}H_{36}N_4O_8$, which is of a greenish colour. The constitution of these bodies is not known.

Chlorophyll is, as the name implies, the green colouring matter of the leaves of plants. It is of special interest and importance from several points of view, but it is an extremely difficult substance to investigate. It is present only in minute quantities even in leaves that are intensely green, and it is always associated with fats, waxes, and other impurities which are soluble in the same solvents and are not easily separated. Also, it readily suffers change.

Chlorophyll is found in all vegetable cells that are concerned with the assimilation of carbon from carbon dioxide; not in others. The process apparently depends upon the presence of chlorophyll, but it is not known how that substance acts. Sachs has advanced the hypothesis that the cells which do not assimilate carbon contain a colourless substance which he called leucophyll, and that, on exposure to light, this body is changed into the green chlorophyll.

With regard to the chemical composition and properties of chlorophyll but little information of a satisfactory character is available. It is uncertain whether there is only one or several different kinds. It appears, however, to be closely allied to hæmatin, the red colouring matter of blood. The formula $C_{34}H_{34}N_4ClFeO_5$ has been ascribed to the latter. Probably both substances are derivatives of pyrrol.



Chlorophyll is always associated with a certain amount of ash constituents from which it cannot be entirely separated, or only with great difficulty. The oxides of calcium, magnesium, iron, and phosphorus predominate. It is uncertain which, if any, of these are essential constituents of the molecule. The presence of iron is at least indispensable to the formation of chlorophyll whether it enters in the composition of the substance or not.

Chlorophyll is an amorphous, neutral body, insoluble in water, but readily soluble in alcohol and other organic solvents. The ethereal solution is strongly fluorescent, *i.e.* it exhibits a vivid green colour by reflected light, and a red colour by transmitted light. The solution may be kept indefinitely in the dark, but rapidly undergoes change on exposure to light. The colour fades, and the substance is broken up into a number of complex products of an acid character.

When ethereal solutions of chlorophyll are shaken up with fuming hydrochloric acid and allowed to settle, the mixture separates into two layers. The upper (ethereal) portion exhibits a yellow colour, and has, in consequence, been called phylloxanthine or xanthophyll; the lower (aqueous) portion is blue, and has, therefore, been called phyllocyanine or cyanophyll. The latter reacts with certain salts—chiefly compounds of iron with organic acids, forming green solutions which closely resemble the colour of the original chlorophyll. A crystalline body called phyllotaonin, $C_{40}H_{38}O_5N_6$, has been obtained from cyanophyll by further treatment with hydrochloric acid and also by the action of alkalis.

The composition and properties of lactochrome, the colouring matter of milk fat, are quite unknown.

Many other colouring matters, both of animal and vegetable origin, might be mentioned, but the examples given above must suffice, as they are of minor importance from the present point of view.

Waxes.—Waxes are unctuous substances very similar to the fats in appearance and general properties. The specific gravity is low, but is generally higher than that of the fats, and the melting points are usually higher. The vegetable waxes are found chiefly as a thin covering, or bloom, on the surfaces of leaves, fruits, and seeds—wheat, maize, peas, etc.—and in larger amounts in the substance of bark and cork. Their presence serves to protect the tissues from the solvent action of water and to increase resistance to hydrolytic changes. They are insoluble, but readily form emulsions in water, and they can be softened by admixture of considerable quantities of that substance.

Waxes are often defined as ethereal compounds of fatty acids with monatomic alcohols of high molecular weight. The natural waxes, however, are not as a rule homogeneous compounds, but mixtures. Various hydrocarbons, free fatty acids, and alcohols are often associated with the ethereal compounds. The ethereal compounds are, of course, saponifiable by the action of alkalis. They yield soaps, but no glycerine.

The fatty acids which are most commonly present belong to the acetic series, and contain from about 12 to 30 atoms of carbon; unsaturated and hydroxy acids also occur. The alcohols have a similar range of carbon atoms, and most of them are saturated compounds. Some waxes, however, contain unsaturated alcohols, and dihydric compounds (glycols) are also known to occur. Spermaceti, which is regarded as a typical wax, consists mainly of cetyl palmitate, $C_{16}H_{31}O_2.C_{16}H_{33}$. The ethereal compound which forms the larger part of Chinese wax is known as ceryl cerotic ester, of which the formula is $C_{27}H_{53}O_2.C_{27}H_{55}$.

Waxes are normally present in admixture with many of the natural fats. To a large extent they are soluble in the same solvents. Fats and waxes are, therefore, extracted together, and are not easily separated. The crude ether extract, obtained in the ordinary course of analysis of feeding stuffs

(p. 47), includes any waxes that may be present. The latter are not digested by animals and have no nutritive value.

Volatile or Essential Oils.—The so-called essential oils or essences of plants are also unctuous substances of low specific gravity—a few are heavier than water. Most of them are insoluble in water, but soluble in alcohol, ether, and other common solvents for fats. They exhibit characteristic aromatic odours, and usually have a strong piquant taste. The presence of essential oils in vegetable matter imparts something of these qualities to it, and often renders it more attractive to animals as food. In other words, they serve as natural condiments. A few, *e.g.* oil of bitter almonds, occur in the plants in the form of glucosides or other non-odorous compounds, but the majority occur as such or mixed with oleoresins.

The essential oils are distinguished from the true fats or fixed oils by the fact that they are volatile. They can be distilled without decomposition and leave no permanent translucent strain on paper. Constitutionally they are very different. They are not glycerides. Some—chiefly the essences of fruits and flowers—are esters, but the acids and alcohols of which they are composed are of low molecular weight, and the latter are monohydric. More commonly they are hydro-carbons, alcohols, phenols, aldehydes, ketones, or acid anhydrides. Nitrogen, or sulphur, or both, enter into the composition of some. The majority are mixtures of several compounds. The following examples will serve to illustrate the nature of the chief constituents of some of the well-known essential oils.

Essence of pineapple contains ethyl butyrate, $C_4H_7O_2.C_2H_5$. Essence of Jargonelle pear contains amyl acetate, $C_2H_3O_2.C_5H_{11}$. Menthol, which occurs in oil of peppermint, is an alcohol. Cinnamic aldehyde, $C_6H_5CH{:}CHO$, is a constituent of the oil of cassia. Thymol, $C_6H_3(CH_3)(C_3H_7)OH$, which occurs in oil of thyme, and eugenol, $C_6H_3(C_3H_5)(OCH_3)OH$, are both phenols. Oil of garlic is allylsulphide, $(C_3H_5)_2S$, and mustard oil is allylisothiocyanate, C_3H_5NCS.

The last occurs in the form of a glucoside, potassium myronate (p. 89), in mustard seeds. In excessive quantity it is liable to set up inflammation in the stomach and bowels of animals, and feeding stuffs which contain mustard seeds (p. 274) are regarded as injurious.

Vegetable Acids.—The juices of fruits, the stems and leaves of most herbaceous plants, and several cultivated roots, are generally more or less acid to test-paper. In certain cases, especially in the unripe condition, they are strongly acid. This condition is due to the presence of acid potassium and calcium salts, of dibasic and free monobasic carboxyllic acids. Neutral salts of the same acids are usually present in considerable quantity in the less acid or neutral plant juices. A slightly acid condition of the food appears to be agreeable to the taste of many of the herbivorous animals, and is probably favourable to the processes of digestion.

The acids may be classified according to the ordinary rules of organic chemistry. A few examples are given below.

(1) *Monobasic Fatty Acids*, $C_nH_{2n}O_2$.—Acetic acid, $C_2H_4O_2$, which may be taken as the type of this group, is perhaps the most widely distributed of all the vegetable acids. It is present either in the free state or as a salt in the juices of nearly all common plants. It is formed in seeds during the process of germination, and in nearly all fermentations of vegetable matter. It is, therefore, found, sometimes in considerable quantity, in brown hay and silage products.

(2) *Hydroxymonobasic Acids.*—Glycollic acid, or oxyacetic acid, $CH_2(OH).COOH$, is found in unripe grapes, in the leaves of wild vine, and many other plants. Like all such acids it has a pleasant ethereal taste.

(3) *Dibasic Acids.*—Oxalic acid, $(COOH)_2$, is probably the commonest member of this group. Considerable quantities of the potassium hydrogen salt are obtained from several varieties of sorrel and rumex. The free acid occurs in boletus, and the acid calcium salt occurs in rhubarb, to which it imparts a characteristic, rather unpleasant, earthy taste. The neutral calcium salt is found in clovers, and most other leguminous plants. The acid and its salts are regarded as deleterious, and, in larger quantity, even poisonous to animals. Malonic acid, $CH_2(COOH)_2$, occurs in beetroot. Succinic acid,

$C_2H_4(COOH)_2$, is of fairly common occurrence, especially in the compositæ and papaveraceæ. It is found in grapes and other fruits, and is one of the products in many different types of fermentation, *e.g.* alcoholic fermentation of sugars.

(4) *Hydroxydibasic Acids.*—Tartronic acid and malic acid are perhaps the commonest members of this group. The former is hydroxymalonic acid, $CH(OH):(COOH)_2$, and the latter hydroxysuccinic acid, $CH_2.CH(OH).(COOH)_2$. Malic acid is the characteristic acid of apples, strawberries, and many other fruits and vegetable products From the present standpoint it is chiefly of interest on account of its relation to asparagine and aspartic acid (p. 52). Tartaric acid, $(CHOH)_2(COOH)_2$, is dihydroxysuccinic acid. It also occurs in many fruits. The potassium hydrogen tartrate called argol separates out from the juice of grapes during the process of fermentation. When purified, this salt is known as cream of tartar.

(5) *Citric Acid.*—The characteristic acid of oranges and lemons is a hydroxytribasic compound corresponding to the formula $C_3H_4(OH)(COOH)_3$.

PART II.—THE REQUIREMENTS OF ANIMALS

CHAPTER VIII

NUTRITION

Composition of Animal Bodies.—The term "nutrition," as applied to animals, may be roughly defined as the building up of their bodies. It includes all the processes of growth, from birth to maturity, of increase in fattening, of repair of the waste which never ceases in any condition during life, and, incidentally, the processes of attrition themselves. The study of these questions belongs primarily to the domain of physiology, but many of them can be approached only from a chemical standpoint. The fundamental considerations are, of course, the chemical composition of the animal bodies, of the food out of which their substance is formed, and the changes involved in the transformation of the latter into the former.

Physiologically, the bodies of animals consist mainly of the skeleton, flesh (including fat and skin), organs or viscera, and the blood and nervous systems. The heart and lungs are situated in the thorax or chest and are called the thoracic viscera. The stomach, gut or intestines and the glands—liver, spleen, pancreas, etc.—connected with the same are situated in the belly or abdomen, and are collectively known as the abdominal viscera.

The skeleton supports the whole structure and gives form to the body. The bones of which it is made up are composed of two kinds of material—the organic matter, which consists mainly of collagen and fat (pp. 40, 77), and the so-called mineral matter, which consists mainly of tricalcic-orthophosphate (p. 11). These two kinds of matter are intimately associated. It is the phosphate of lime which gives rigidity to the bones. The collagen acts as a kind of cement and holds the particles of mineral matter together.

The relative proportions of mineral and organic matter vary considerably according to the age of the animal. When the animals are young, the percentage of phosphate of lime is comparatively small, but it increases rapidly as they approach maturity. In general, the proportions of mineral and organic matter are roughly about five of the former to four of the latter. The following analysis shows the average composition of mamalian bones in the fresh or green state.

AVERAGE COMPOSITION OF BONES—PER CENT.

Water	6·7		6·7	
Organic matter .	40·0	Fat	14·6	
		Ossein	25·4	= 4·0 % nitrogen
Ash	53·3	P_2O_5	22·3	= 48·7 % $Ca_3(PO_4)_2$
		CaO	29·2	
		MgO.F, etc.	1·8	
	100·0		100·0	

The red flesh or muscular tissue, the skin, organs, nerves and vessels, all consist mainly of protein compounds. Even cartilage and the horny matter of hoofs, etc., are of this nature (p. 78). In the soft parts, the protein is associated with a large amount of water and, usually, with a small amount of fat. It is commonly believed that the flesh of lambs, calves, and young animals generally is of a more watery character than that of the corresponding animals, sheep, oxen, etc., in the mature condition. According to the analyses of Atwater and Bryant[1] the ratio of water to protein is very much the same in the corresponding parts of various animals; and it does not differ very widely even in the different organs and parts of

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[1] Bul. 28 of Exper. Stations, U.S. Dept. of Agriculture.

their bodies, as will be seen from the figures in the following table.

	Water (per cent.).	Protein (per cent.).	Ratio.
Side of Beef	49·4	14·8	3·4—1
Side of Veal	55·2	15·6	3·5—1
Side of Mutton	43·3	13·0	3·3—1
Side of Lamb	47·0	14·1	3·3—1
Side of Pork	30·4	8·0	3·8—1
Beef Kidneys	63·1	13·7	4·6—1
Sheep's Heart	69·5	16·9	4·1—1
Sheep's Lungs	75·9	20·2	3·7—1
Pig's Liver	71·4	21·3	3·3—1

Large quantities of fat are always found in the region of the kidneys which it surrounds and encloses. Fat also occurs in masses or layers in other parts of the body. As previously mentioned, it enters into the composition of bones, and is usually associated, to some extent, with the protein in other tissues.

Taking the whole bodies of animals, the ratio of fat to protein varies very widely. In store oxen it is about one to one; in fat pigs it is about four to one. A fat sheep may contain about twice as much fat as a lean one. It is very difficult, therefore, to make any exact comparison between animals of different kinds; but allowing for the variation due to condition it may be said that, in general, pigs contain more fat than sheep, and sheep more than oxen in proportion to their weight.

It will be seen that the chemical composition of animal bodies varies with the kind, age, and condition. The ordinary limits of variation and the average for all farm animals are as follows:—

Composition of Animal Bodies—Per Cent.

	Ordinary Limits.	Average. Whole.	Average. Dry.	
Water	40 to 60	50	—	
Fat	15 " 45	33	66	94
Protein	10 " 16	14	28	
Ash	1·5 " 4·5	3	6	
		100	100	

Under ordinary circumstances, water forms about half the total weight of the body. The dry matter consists almost entirely of fat and protein. The percentage of mineral matter is relatively small.

Functions of the Organs.—The heart and lungs are respectively the active organs of circulation and respiration. The abdominal viscera are mainly concerned with the digestion and absorption of the food. The material absorbed is distributed to all parts of the body by the blood. Excess of water, certain products of katabolism, soluble salts, etc., are eliminated from the blood by the kidneys and discharged as urine. The chief functions of the nerves are sense (perception) and control.

The process of digestion begins in the mouth. By mastication the food materials are mechanically disintegrated and mixed with saliva. This fluid has a faintly alkaline reaction and contains a ferment called ptyalin—an amylase—which acts upon starchy materials and converts them into sugars (p. 87).

In the stomach, the food is acted on by the gastric juice which has an acid reaction. It contains a small amount (from 0·2 to 0·5 per cent.) of hydrochloric acid and several enzymes. Pepsin, the most important of these, is a proteolytic ferment. It acts upon proteins and converts them into the soluble, diffusible proteoses and peptones (p. 71).

From the stomach, the partially digested food passes through the duodenum, where it is mixed with the secretions of the liver and the pancreas, and so into the intestines.

The secretion from the liver is called bile. Like the saliva, it is faintly alkaline, and it contains ferments of the lipase type which act upon fats, and saponify them (p. 40). Apparently the fats are first emulsified, *i.e.* broken up into extremely minute particles which remain diffused through the aqueous fluid, but they are probably all saponified before absorption.

The pancreatic juice is also alkaline, and contains several ferments which enable it to perform, to some extent, the functions of all the digestive juices previously mentioned. It acts upon carbohydrates which have escaped the action of the saliva, upon fats which have not been completely saponified by the bile, and upon proteins which have not been completely peptonised by the gastric juice. The action of trypsin, the chief proteolytic ferment of the pancreatic juice, is not exactly the same as that of pepsin. Like the latter, it forms proteoses and peptones, but the action proceeds further and results ultimately in the formation of amino-acid compounds; whereas very little, if any, amino-acids are formed even by prolonged peptic digestion.

It is not known whether any of the digestive juices contain an active ferment of the cytase type. It is certain that a variable but usually considerable amount of the cellulose of the food disappears in the process of digestion by herbivorous animals, but this may be due to the action of bacteria. Probably the intestinal gases are mainly formed in this way.

As a result of all these processes, the food is reduced finally to the fluid condition. This fluid is of milky consistency and is called chyme. Digestion is then complete. The chyme passes downwards, and the soluble and diffusible compounds which it contains are absorbed by hair-like structures, called villi, which project from the walls of the intestines.

It appears, then, that the process of digestion as a whole consists in the reduction of the solid constituents of the food to the fluid condition. Any substance or portion which is not acted on by the digestive juices, or which is not rendered soluble and diffusible, cannot be absorbed, and is said to be indigestible. This indigestible matter passes downwards through the intestines, and, together with any excess of digestive juices, effete membranes, etc., is excreted as fæces.

Digestibility.—The term "digestibility" refers to the thoroughness and rapidity with which the constituents of the food are transformed into chyme. If one of two different foods or portions of food undergo this transformation more rapidly or more thoroughly than another, under similar conditions, it is said to be more digestible.

The digestibility of a food can be estimated from the amount excreted as fæces. For example, in an experiment of this kind, an animal consumed 25 lbs. of hay, and dropped, on the average, 60 lbs. of fæces daily during the time (about three weeks) the experiment lasted. The composition of these products was found, on analysis, to be as follows :—

	Hay (per cent.).	Fæces (per cent.).
Moisture	14·2	84·0
Ash	5·8	2·4
Organic matter	80·0	13·6
	100·0	100·0

The total quantities of organic matter consumed and excreted were therefore—

$$\frac{80 \times 25}{100} = 20{\cdot}0 \text{ lbs.} \qquad \frac{13{\cdot}6 \times 60}{100} = 8{\cdot}16 \text{ lbs.}$$

The digestibility of the organic matter was then calculated thus—

$$\frac{100\,(20{\cdot}0 - 8{\cdot}2)}{20} = 59{\cdot}0 \text{ per cent.}$$

This figure—59 per cent.—is called the coefficient of digestibility of the organic matter in that food. The coefficient of digestibility of the protein, fat, and other constituents can be determined in a similar manner. The data required in each case are the quantities of the particular ingredient consumed and excreted.

There are, of course, considerable practical difficulties connected with experiments of this kind. Suitable arrangements must be made for the collection, weighing, and sampling of the fæces; and care must be exercised to prevent it becoming mixed with urine, litter, or other extraneous matter.

Owing to the difference in the capacity of the stomach and intestines, the time required for the undigested portion of the food to pass out of the body varies considerably in different types of animals. For ruminants, it is estimated at three or four days, for pigs thirty to forty hours, and for horses about twenty-four hours. The only way, therefore, to ensure proper correspondence between the food consumed and the fæces excreted is to extend the time of the experiment.

Concentrated foods, such as oats, oil-cakes, etc., cannot be used alone, but must be fed to the animal along with hay or other bulky fodder, the digestibility of which has been previously determined. By subtracting the amount of protein in the bulky fodder from the total amount in the ration consumed, and subtracting the amount of protein corresponding to it from the total amount in the fæces, the data are obtained for calculating the digestibility of the protein in the concentrated food.

The fact that the fæces contains effete bowel membranes and other ingredients not directly derived from the food tends to vitiate the results. No means is known by which this difficulty can be overcome; but the amount of such ingredients is probably small and approximately constant. In practice it is ignored.

Even when all the necessary precautions are observed, the results obtained in different experiments are not entirely concordant, and the coefficients of digestibility are not very reliable. Only those which represent the average of a large number of trials can be accepted.

The digestibility of the protein in various foods has also been determined by methods of artificial digestion, *i.e.* by exposing the food successively to the action of pepsin and trypsin under conditions which correspond, as far as possible, to those which obtain in the animal body. The soluble products are filtered off, and, after washing, the nitrogen is determined in the residue. Though fairly satisfactory, the results are not considered so reliable as those derived from experiments on living animals. It has not, as yet, been found practicable to determine the digestibility of the fat or carbohydrates by such methods.

The undigested portion of the food consists, perhaps mainly, of those constituents which, owing to their peculiar physical or chemical condition, resist the action of the ferments; but it also includes some of the more readily digestible constituents which are so enclosed in the cells of the more resistant material that they are protected from the action of the digestive juices.

Any imperfection of the teeth or other cause which interferes with thorough mastication tends to reduce the digestibility of the food. On the other hand, mechanical grinding, which ruptures the cells and exposes a larger surface to the action of the digestive juices, perceptibly increases the digestibility of the harder fodders. Complete disintegration increases the digestibility very largely.

The percentage of cellulose in vegetative organs increases very rapidly as the plants develop. As a result of various physiological and chemical changes it soon becomes harder and more fibrous, and the digestibility both of this and other constituents is reduced. For example, the digestibility of the total organic matter in grass cut at the middle of May is about 78 per cent., a month later it is reduced to about 65 per cent., and at the end of June, when the grass is cut for hay, it is only about 60 per cent.

The digestibility of the constituents of seeds of plants grown under normal conditions is high and fairly constant. In fodders which consist of the vegetative organs of plants the coefficients of digestibility are lower and much more variable. Apart from substances which are by-products of industrial processes, the widest variations are found in preserved fodders, *e.g.* hay, silage, etc. Any losses due to soaking with rain, or to fermentation, fall most heavily upon the soluble and readily digestible portions. The average coefficients of digestibility for such products are not, therefore, of much value for particular samples unless all the circumstances are known.

When the food consists of a single substance of a suitable kind, the digestibility is independent of the amount of the ration. For example, the digestibility of the organic matter of hay was found to be practically the same—about 60 per cent.—when oxen were fed upon it at the rate of 15, 20, and 25 lbs. per day, respectively.

The same is true also of mixed fodders, provided the relative proportions of the different constituents are properly balanced; but excess of any one ingredient affects the digestibility of all to a considerable extent. The addition of fodders rich in carbohydrates—especially those of a readily digestible nature, *e.g.* starch and sugar—to a fodder poor in protein produces an apparent reduction in the digestibility both of the nitrogenous and non-nitrogenous nutrients. At all events, larger amounts of both are found in the fæces. It is probable, however, that the increased amount of nitrogenous matter found in the fæces is not derived from the food but from the digestive juices which are secreted in larger quantities under these circumstances and possibly, in part, from the mucous lining of the intestines. The diminution of the digestibility of the non-nitrogenous matter is real. It has been suggested that bacteria, which play an important part in the process, are able to obtain a sufficiency of nourishment in the more readily digestible substances which have been added and do not, therefore, act so strongly upon the coarser fodder. This hypothesis is open to very serious objections; but whatever the true explanation may be there can be no doubt as to the fact.

The addition of considerable quantities of carbohydrates does not affect the digestibility of foods that are relatively rich in nitrogenous matter. It is only when the amount of carbohydrates is excessive, *i.e.* more than about ten of the latter to one of nitrogenous matter, that this effect is produced. The tendency of large quantities of carbohydrates to reduce the digestibility of other foods can be corrected by adding more nitrogenous matter till the balance is restored; and it is found that amides are as effective as true protein in this respect.

Excessive quantities of fat are not easily digested by the herbivora, and the addition of such to other food tends also to reduce the digestibility of all the constituents by protecting them from the action of the aqueous digestive juices. The addition of small quantities of fat to foods that are naturally poor in that ingredient has no perceptible effect on the digestibility, provided the fat is thoroughly broken up by mixing with the other foods. It is considered inadvisable that the amount of fat should be more than about 10 per cent. of the nutrients.

The coefficients of digestibility for any food depend, to some extent, upon the digestive capacity of the animals experimented on. The most striking differences are those observed when ruminants are compared with non-ruminants. Very little difference has been observed as between cattle and sheep. When pigs and horses are compared, the differences are more marked, but these two animals are not largely fed on the same kinds of food.

So far as the more concentrated and readily digestible foods are concerned, except in regard to fats, the differences between ruminants and non-ruminants are so small that they may be ignored in practice; but in the case of the coarser fodders, the differences are more considerable and must be taken into account. This may be attributed largely to the influence of the hard, fibrous tissues in the latter. Cattle and sheep, by virtue of their more complex and elaborate digestive apparatus, are better adapted than horses to deal with this kind of material, and they digest a larger proportion of the crude fibre. It is probably also on this account that a much larger percentage of the fat in coarse foods is digested by sheep and cattle than by horses. The latter have naturally a smaller capacity for the digestion of fat, and the difference is accentuated when that ingredient is protected by much fibrous tissue. Ruminants also digest a somewhat larger proportion of the soluble carbohydrates (starch, etc.), but very little difference has been observed in regard to protein.

These facts may be illustrated by comparing the digestibility coefficients of the several ingredients of the food for horses and cattle.

DIGESTIBILITY COEFFICIENTS.

	Meadow Hay.				Oats.			
	Protein.	Fat.	Carbohyd.	Fibre.	Protein.	Fat.	Carbohyd.	Fibre.
Cattle	57	50	65	60	76	80	75	30
Horses .	58	18	58	40	80	70	75	30

Of course no two animals of the same kind give absolutely identical results; but the differences between individuals, provided they are normal and healthy, are small. Apart from this, no difference has been observed as between the different breeds of the same kind of animal. Within limits, the age of the animal has no effect upon the digestibility of the food; and, contrary to what is often supposed, the coefficients are practically the same when the animals are at work as when they are at rest.

Since the processes of digestion are caused by ferments, anything which inhibits or interferes with their action must tend to reduce the digestibility of the foods. Excess of common salt is the only substance likely to produce such effects. No other antiseptics are ever added to cattle foods. They are not required.

A certain amount of water is required to form the digestive juices, to dissolve the products, and for other purposes; but if a large quantity is drunk immediately before or after a meal, it may tend to interfere with gastric digestion by unduly diluting the gastric juice and by temporarily lowering the temperature of the stomach.

Condiments and spices of various kinds are said to increase digestibility. These substances are not, themselves, digestive agents, but they may tend to increase the flow of digestive juices in the mouth and stomach. They are probably advantageous in fattening chiefly as a means of inducing the animals to consume more food. For this purpose, sugar and salt in moderate quantities are amongst the most useful condiments.

The digestibility of green fodders is not affected by drying, *e.g.* by making grass into hay, provided that no loss occurs in the process. The dried products are, however, more difficult to masticate than the fresh, juicy material, especially if the plants are old and contain much fibre, and a certain loss of energy is involved (p. 154).

Metabolism.—The constituents of the food which are absorbed by the villi (p. 102) undergo further changes within the walls of the intestines; but these changes are of a reverse kind. Substances of more complex character are regenerated out of the comparatively simple products to which the original constituents of the food are reduced by the processes of digestion. Probably proteoses, peptones, and possibly also amino-acids, are reconverted into albumins, globulins, etc., and the fatty acids into fats. It is uncertain whether these changes take place to a large extent within the walls of the intestines or subsequently. However this may be, the absorbed materials soon pass into the blood.

The small veins with which the intestines are abundantly supplied unite to form larger ones, and these in turn unite to form still larger vessels which lead ultimately to the heart. The great arteries leading from the heart branch again and again, gradually diminishing in size, and end finally in a close meshwork of fine capillaries which are intimately associated with all the tissues throughout the body. The walls of these capillary vessels are necessarily very thin and some of the blood plasma exudes through them. This fluid is then called lymph. It fills up all the interstices between the cells and thoroughly bathes the tissues which are restored and nourished by the substances present in the lymph and which are derived from the food.

The lymph is drained off by a special set of vessels known as the lymphatics. The smaller lymphatics, which are of capillary size, unite to form larger vessels, and ultimately a junction is formed with one of the larger veins by which the blood returns to the heart. From the heart the blood goes to the lungs, then back to the heart, and out again through the arteries as before.

In the lungs, the blood is exposed to the oxidising action of the air which is inhaled by them ; and when sent out again from the heart, it carries the oxygen in the form of a compound —oxyhæmoglobin—to all parts of the body. The tissues are thus oxidised, and the carbon dioxide and water which are formed are given up when the blood again returns to the lungs. The nitrogenous matter is not completely oxidised. No free nitrogen is liberated. This element appears in the form of comparatively simple compounds—chiefly urea, uric acid and hippuric acid (pp. 53, 54, 55). These pass into solution in the blood, from which they are eliminated by the kidneys, and are discharged in the urine.

It appears, therefore, that two opposite kinds of change are constantly going on in animal bodies. The tissues are exposed to a continuous process of oxidation by which they are gradually attenuated. At the same time, the blood is constantly being enriched by materials derived from the food, and these are used to repair the waste, and form new tissues. These two processes of elaboration and attrition constitute the very essence of life as we know it. A condition of equilibrium may be established between the two; but if the former takes place faster than the latter, the mass of the body will be increased, and *vice versâ*.

It is not a little remarkable that these two opposite kinds of change should be carried on by the same agency. It is difficult to understand why the oxidisable material derived from the food, and the oxidising agent formed in the lungs, do not react, when, *ex hypothesis*, they are both present in the blood at the same time. As a matter of fact many authorities hold that they do react, *i.e.* that the food materials are directly oxidised in the blood, and merely serve to protect the permanent tissues from oxidation. According to this view, a sufficient quantity of food materials would afford complete protection, and any less quantity only a partial protection. In the latter case there would be a proportional loss of body weight owing to oxidation of the tissues. On the other hand, if the food materials were more than sufficient to reduce the oxyhæmoglobin, the excess could be stored up as tissue, and the mass of the body would be increased.

As against this, however, there is reason to believe that the tissues actually do suffer continuous oxidation, and are as continuously renewed in the manner described. Otherwise, a sufficiency of fat and carbohydrate food would completely protect the protein tissues from oxidation; but it has been proved that such is not the case. Huxley inclines to the view that the food material is not directly oxidised in the blood, but only after it has been deposited as tissue. In that case, probably, the fat and carbohydrates of the food would afford no protection to the protein tissues at all, whereas it has been proved that they do protect them against oxidation to a very considerable extent (p. 133).

The two theories are not necessarily irreconcilable, and, in the author's opinion, it is difficult to resist the conclusion that to a certain extent both are correct, *i.e.* that some of the food material is directly oxidised in the blood, and that some is used to repair the waste due to oxidation of the tissues.

So far as repair of the waste or formation of new tissue is concerned, it is at once obvious that nitrogenous matter (protein) cannot be formed from non-nitrogenous matter (fat and carbohydrates). It is essential, therefore, that an amount of nitrogenous matter adequate for these purposes should be supplied in the food. This conclusion is amply borne out by numerous experiments. If the supply of protein in the food is insufficient, the animal dies of nitrogen starvation.

It has further been shown that the protein must be of the right kind. Gelatine, for example, will not do. It tends to minimise the waste, but by itself it cannot wholly repair it. Gelatine contains no tyrosine, tryptophane, or cystin (p. 52), and is probably lacking also in other radicles that are essential for the formation of the complex proteins of which the animal's body is built up. Indeed there is some reason to believe that any one of the vegetable proteins is not by itself adequate for the purpose. It was found that mice died of nitrogen starvation when zein (p. 74) was the only nitrogenous constituent of the food. The proteins of any food are rarely, if ever, all of one kind, but often one predominates. If the proteins are derived from several kinds of food, the chances are increased that the products into which they are resolved by the processes of digestion will furnish all the constituents required. These constituents can then be selected in the proportions required; if any one or portion of one is not utilised in this way, it will, of course, pass into the blood and be further oxidised. This is one reason—there are others—why the food should be of a mixed and varied character.

The question then arises whether the non-protein nitrogenous compounds (amides) are of any value for the nutrition of animals. On this point the opinions of authorities are divided. If it be true, as is now generally believed, that the proteins of the food are completely resolved into amino-acids by tryptic digestion, it follows that animals must possess the power of re-forming protein from these compounds. We should therefore expect that a mixture of amino-acids in which all the necessary ingredients are present in the proportions required could be substituted for true protein, and would have the same nutritive value. It is, however, extremely difficult to ensure that any artificially prepared mixture contains all the necessary ingredients. It has been shown that the products, as a whole, resulting from the acid hydrolysis of proteins (p. 70) are not an efficient substitute for that substance.

When amides are ingested, they are rapidly absorbed, and are oxidised in the animal's body; and it is said that dogs and rats have been kept alive for months on rations which contained no true protein, but it is not asserted that the animals thrived. The whole question requires further investigation. At present, the general consensus of opinion is to the effect that amino-acids do not form an efficient substitute for the whole of the protein.

It is not quite certain that the proteins of the food are wholly and completely resolved into amino-acids by the processes of digestion. Proteoses, peptones, and peptides, are readily soluble and diffusible, and it is more than probable that some at least of the nitrogenous matter of the food is absorbed in that form.

When amino-acids are ingested along with true protein they act to some extent in the same manner. It is not known whether they are actually converted into true protein by the action of bacteria, or whether their presence serves merely to protect the true protein from oxidation. There is no doubt that the addition of amides to a food poor in protein increases the nutritive value of the food.

The amides of the common foodstuffs—roots, tubers etc.—probably do not contain all the ingredients necessary for the formation of animal proteins; but it is believed that they are not entirely without nutritive value. It is generally agreed, however, that the nutritive value of the amides of the food is much lower than that of the true protein.

It has been shown (p. 111) that the protein of animal bodies cannot be formed from the non-nitrogenous matter (fats and carbohydrates) of the food. The converse, however, is not true. Under certain conditions, body fat may be formed from the protein of the food. A certain amount of protein is required to repair the waste due to oxidation. If there be any excess in the food, a small proportion of it can be stored up as tissue, and fat may be formed from the remainder.

It was at one time thought that all the body fat was normally formed in this way. It is now known that, under ordinary circumstances, it is mainly formed from the fat and carbohydrates of the food. The process appears to be quite independent of the protein. It may take place not only when there is an insufficiency, but even in the total absence of protein in the food. In other words, an animal body may gain fat and lose protein (not relatively, but absolutely) at the same time.

The fats do not suffer disintegration to the same extent as the proteins in the process of digestion. At most they are resolved into glycerine and fatty acids, and are re-formed by combination of these ingredients after absorption. No doubt, owing to partial or complete oxidation of some of the acids and readjustment of the radicles, the re-formed products differ considerably from the original fat of the foods; but they often retain something of their character. Beef made from cattle that have been fed largely on cod liver oil sometimes has a faintly fishy taste. The melting point and other characteristic properties of butter fat are very directly influenced by the amount and character of the fat in the food.

Numerous experiments show that body fat may also be formed from the carbohydrates of the food. All these compounds are easily converted into sugars, and to a large extent they are so converted in the process of digestion. Probably all the body fat formed from carbohydrates passes through the stage of sugar. It must not be forgotten, however, that the methane of the intestinal gases is also derived from the carbohydrates.

There can be little doubt that much of the carbohydrate absorbed is directly oxidised in the blood. These compounds suffer oxidation more readily than any other constituent of the food, and it is only when they are present in excess, *i.e.* when there is more than can be oxidised, that any can be stored up as body fat. The fat of the food is probably not oxidised until all, or nearly all, the carbohydrates have been disposed of. In other words, the carbohydrates protect the fat from oxidation; but if there be not enough carbohydrate to do this, then some of the fat also is oxidised, and it is only the excess that can be stored up as body fat.

It may be said, therefore, that it is from the excess of non-nitrogenous nutrients—fat and carbohydrates taken together—that body fat is formed, and then only if there is excess of these ingredients over and above what naturally suffers oxidation. Under these conditions, *i.e.* in the presence of excess of fat and carbohydrates, the oxidation of protein is reduced to a minimum. It is protected by the non-nitrogenous nutrients. But if the fat and carbohydrates are, together, insufficient to protect it, increased oxidation of protein follows immediately. If the food absorbed contain more protein, fat, and carbohydrates than are oxidised in the blood, the excess may be used to repair the waste of tissue, and can be stored up in the body. Protein, of course, is only formed from nitrogenous matter, but body fat may be formed from all or any of the constituents. If the protein, fat, and carbohydrates are together not equal to what is naturally oxidised, the waste cannot be repaired and the animal loses weight.

CHAPTER IX

STATICS

Oxidation.—In the preceding chapter, the question of nutrition was considered from a purely qualitative point of view. In order to understand the quantitative relationships it is necessary to consider the potential energy of the food as a whole and of the several constituents.

By potential energy of the food is meant the energy which is liberated, *i.e.* converted into the kinetic form, when the food is oxidised. The amount of potential energy of any food must therefore bear some relation to the amount of oxidation of which the food is capable. All the constituents—protein, fat, and carbohydrates—of the food are already partially oxidised, *i.e.* they contain some oxygen, but in very different degree, and require different amounts of oxygen to complete the change. This may be seen, perhaps most clearly, from the percentage composition of the compounds.

	Fats.			Carbohydrates.		
	Olein.	Stearin.	Palmitin.	Starch.	Cane Sugar.	Glucose.
Carbon .	77·3	76·9	75·9	44·4	42·1	40·0
Hydrogen .	11·8	12·3	12·2	6·2	6·4	6·7
Oxygen .	10·9	10·8	11·9	49·4	51·5	53·3
	100·0	100·0	100·0	100·0	100·0	100·0

There is but little difference in the percentage composition of the several kinds of fat and of the several kinds of carbohydrate; but the percentage composition of the former is very different from that of the latter. The fats contain only about 11 per cent. of oxygen; the carbohydrates contain about 50 per cent. There is also but little difference in the percentage composition of the different kinds of protein (p. 66). They all contain about 22 per cent. of oxygen, and are therefore intermediate in this respect between the fats and carbo-hydrates.

If the glyceride of stearic, palmitic, and oleic acids jointly be taken as representing the average composition of the fats, and cane sugar as representing the carbohydrates, the amount of oxygen required for complete oxidation of these two classes of compounds can be calculated from the formulæ as follows:—

Fat . . . $C_{55}H_{104}O_6 + 78O_2 \rightarrow 55CO_2 + 52H_2O$
$2496 \div 860 = 2{\cdot}9$
Cane sugar . $C_{12}H_{22}O_{11} + 12O_2 \rightarrow 12CO_2 + 11H_2O$
$384 \div 342 = 1{\cdot}12$

For protein the calculation must be made from the percentage composition—

Carbon $32 \times 53 \div 12 = 141{\cdot}\dot{3}$
Hydrogen $16 \times 7 \div 2 = 56$
Sulphur $32 \times 2 \div 32 = 2$

100 parts protein require	199·3 parts of oxygen
less what it already contains	22·0
	177·3

It will be seen that for complete oxidation—

1 part of fat requires	2·90	parts of oxygen
1 „ protein requires	1·77	„ „
1 „ carbohydrate requires	1·12	„ „

Of the constituents absorbed from the food, the fat alone suffers complete oxidation in the animal's body. The residue resulting from the oxidation of protein consists mainly of urea. A certain amount of methane is formed from the carbohydrates. Both of these compounds are oxidisable, and the amounts of oxygen required must be deducted from the amounts previously calculated in order to find how much oxygen is required for the oxidation of the constituents of the food.

One hundred parts of protein contain 16 parts of nitrogen, and 16 parts of nitrogen are equal to 34·3 parts of urea.[1] Therefore 1 part of protein yields 0·343 parts of urea.

$$N_2H_4CO + 3O \rightarrow 2H_2O + CO_2 + N_2$$

60 parts of urea require 48 parts of oxygen.

Therefore 0·343 parts of urea require 0·27 parts of oxygen. This amount is to be deducted from that previously calculated for complete oxidation, giving [1·77 — 0·27] = 1·5 parts of oxygen for each part of protein oxidised in the animal's body.

It has been found by experiments in the respiration chamber (p. 130) that about 0·03 parts of methane are formed from each part of carbohydrate (starch). The corresponding amount of oxygen is easily calculated.

$$CH_4 + 2O_2 \rightarrow CO_2 + 2H_2O$$

Sixteen parts of methane require 64 parts of oxygen, therefore 0·03 parts (equal to 1 part of carbohydrate) require 0·12 parts of oxygen; to be deducted from the amount required for complete oxidation, giving [1·12 — 0·12 =] 1·0 parts of oxygen required for each part of carbohydrate oxidised in the animal's body.

It appears, therefore, that each part of fat absorbed into the animal's system can consume 2·9 times as much oxygen as each part of carbohydrate, and each part of protein 1·5 times as much oxygen as each part of carbohydrate.

The investigations described above are cited by way of explanation of what follows, rather than for the value of the results as such. The potential energy does not correspond exactly with the amount of oxygen required for oxidation. It depends partly on the state of combination of the elements.[2]

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[1] $N_2H_4CO = 28 + 4 + 12 + 16 = 60$

$60 \times 16 \div 28 = 34{\cdot}3$

[2] The heat of combustion of isobutyl alcohol, $(CH_3)_2CH.CH_2OH$, is 661·5 Cal., and that of trimethyl carbinol, $(CH_3)_3COH$, is 643·5 Cal. The two substances are isomeric, *i.e.* they have the same percentage composition and the same molecular weight; the difference, 18° C., in the heats of combustion is due to the way in which the atoms are combined.

Calorimetry.—The true measure of the potential energy of the food, according to definition (p. 114), is the amount of heat developed by the oxidation. This is determined by means of an apparatus called a calorimeter.

Several different forms of calorimeter are in use; but they all consist essentially of a platinum shell or bomb submerged in water. The substance to be tested is introduced into this bomb along with compressed oxygen gas and ignited by means of electric sparks. The heat produced by the combustion is communicated to the water outside, and the rise of temperature is noted. A sectional drawing of the instrument, as actually used, is shown in the illustration[1] (Fig. 7). The mass and specific heat of the apparatus, as well as the mass of the water and of the substance burned, must, of course, be taken into account in an experiment of this kind.

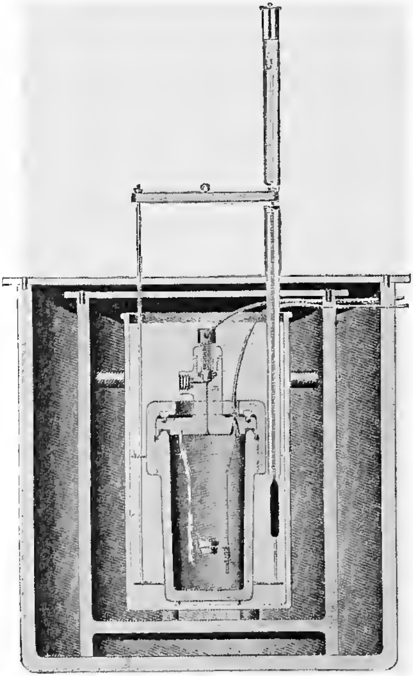

FIG. 7.—Atwater's Calorimeter.

The results are generally expressed in terms of the amount of heat required to raise the temperature of 1 gram of water 1° C. This unit, called a *calorie*, is too small for physiological investigations, and the *kilo-calorie* is often used instead.

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[1] Bulletin No. 21, Office of Experiment Stations, U.S. Department of Agriculture.

A kilo-calorie is 1000 small calories, *i.e.* the amount of heat required to raise the temperature of 1000 grams of water 1° C.

In this country the metric system is used only for scientific purposes; the standard of mass employed in commerce and agriculture is one pound. This standard is adhered to throughout this book, and it is convenient, therefore, to define the unit of heat, for present purposes, in terms of the same unit of mass. The pound-unit is the amount of heat required to raise the temperature of 1 lb. of water 1° C. The "kilo-pound-unit," which may be briefly designated by the symbol "kt.," is the amount of heat required to raise the temperature of 1000 lbs. of water 1° C. This kilo-pound-unit gives conveniently small numbers which are easily compared with those of the metric system.[1]

HEAT OF COMBUSTION (PER LB.) OF PROTEINS, AMIDES, FAT, AND CARBOHYDRATES FROM SEVERAL SOURCES.

Proteins.

	Kt.		Kt.
Crystallised albumin	5·672	Wool	5·564
Egg albumin	5·735	Peptone	5·299
Serum albumin	5·918	Plant fibrin	5·918
Hæmoglobin	5·885	Legumin	5·793
Muscle	5·663	Mean	5·731
Milk casein	5·867		

Amides.

	Kt.		Kt.
Urea	2·542	Alanine	4·355
Uric acid	2·750	Leucine	6·525
Hippuric acid	5·668	Tyrosine	5·915
Creatin	4·275	Asparagine	3·514
Glycol	3·129	Mean	4·318
Sarcosine	4·506		

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[1] In the units of the metric system, the heat of combustion of starch is 4·1825 kilo-calories per gram; in terms of the unit defined above, it is 4·1825 kilo-pound-units per pound. In other words, the heat developed by burning 1 gram of starch will raise the temperature of 1000 grams of water 4·1825° C.; and the heat developed by burning 1 lb. of starch will raise the temperature of 1000 lbs. of water 4·1825° C.

Animal Fats.

	Kt.		Kt.
Horse fat	9·410	Goose fat	9·345
Oxen fat	9·357	Duck fat	9·324
Sheep fat	9·406	Butter fat	9·398
Pig fat	9·380		

Vegetable Fats.

	Kt.		Kt.
Rape seed oil	9·619	Ether extract of various seeds	9·467
Poppy seed oil	9·442	Straw	8·198
Olive oil	9·328		

Carbohydrates.

	Kt.		Kt.
Arabinose	3·722	Starch	4·183
Glucose	3·743	Cellulose	4·185
Fructose	3·755	Dextrine	4·112
Cane sugar	3·955	Inulin	4·134
Lactose	3·952	Glycogen	4·191
Maltose	3·949	Mean	3·99

N.B.—The above figures may be read as kilo-calories per gram, instead of kt. per lb.

1 kilo-calorie (1 C.) = 0·0022 kilo-pound-units.
1 kilo-pound-unit (1 kt.) = 454·0 kilo-calories.

It will be seen from the figures given in the table above that there is not much difference in the heat of combustion of the several kinds of protein. The highest—that of plant fibrin—is 5·918 kt. and the lowest (excepting peptone and wool)—that of muscle—is 5·663 kt. The mean of these two, 5·79 kt., may be taken as the average heat of combustion of the proteins.

The heat of combustion of the fats varies from about 9·3 to 9·6 kt., but that of straw is only 8·2 kt. The average for animal fats and those of oily seeds is generally taken as 9·4 kt., for those of cereals and other seeds 9·0 kt., and for hay, straw, and coarse fodders generally 8·5 kt.

The bihexose sugars have a slightly higher value than the hexoses, and that of the amyloses or polysaccharides is still higher. The figure 4·1 kt. is generally taken as the average for all the carbohydrates, but when sugary foods, such as turnips, molasses, etc., are to be compared with those which contain a large amount of starch, *e.g.* potatoes, barley, etc., it is safer to take 3·9 kt. for the former and 4·2 kt. for the latter.

These conclusions may be briefly summarised as follows :—

		Heat of Combustion.	
		Kt.	Mean kt.
Fats	Of oily seeds and animal fats	9·4	9·0
	Of cereals and other seeds	9·0	
	Of hay, straw, and coarse fodders	8·5	
Proteins, except peptones		5·8	5·8
Carbohydrates	Starch and cellulose	4·2	4·0
	Sugars	3·9	

The heat of combustion of any food as a whole is often called the *total fuel value* of the food. It can be determined by burning the substance in the calorimeter as described above. For a sample of meadow hay it was found to be 3·65 kt. per lb. But it is not necessary to make a separate determination for each specimen. When the composition is known, the fuel value can be calculated by means of the factors given above. Thus the heat of combustion of protein is 5·8 kt. per lb., and meadow hay contains 10 per cent. of that ingredient; so we have 10 × 5·8 = 58 kt. as the fuel value of the protein in 100 lbs. of meadow hay. The values for the other ingredients may be found in a similar manner and the whole calculation set down as follows :—

TOTAL FUEL VALUE OF MEADOW HAY.

Constituents.	Per cent.		Factor.		Fuel value kt.
Oil	2·45	×	8·5	=	20·82
"Albuminoids" (proteins)	10·0	×	5·8	=	58·00
Carbohydrates	42·0	×	4·2	=	285·60
Crude fibre	26·0				
	Total fuel value				364·43

The T.F.V. of meadow hay is, therefore, 3·6443 kt. per lb., *i.e.* when 1 lb. of this hay is burned in a calorimeter it gives out enough heat to raise the temperature of 3644·3 lbs. of water 1° C.

Available Energy.—The T.F.V., however, is not the true measure of the nutritive value of the food. It is obvious that any substance that is not oxidised gives out no heat at all; and any substance that is only partially oxidised gives out only a part of its heat. A more or less considerable part of the food —the indigestible matter—always remains unoxidised and is excreted as fæces. The protein and carbohydrates of the digested portion are not completely oxidised in the animal's body. The residual products derived from the former are excreted in the urine, and those derived from the latter pass out as gases.

In order to estimate the physiological heat value of the food, *i.e.* how much of the potential energy is converted into the kinetic form of heat in the animal's body, the fuel values of the residues—the dung, urine, and gases—must be deducted from the total fuel value of the food. In the case under consideration the figures are—

Food. (Kt.)		Dung. (Kt.)		Urine. (Kt.)		Gases. (Kt.)		Physiological value. (Kt.)
3·65	−	(1·61	+	·035	+	0·173)	=	1·83

It will be noticed that though the total potential energy of the food is 3·65 kt. per lb., only 1·83 kt.—about half the total amount—is *available* to the animal.

The fuel values of the residues cannot, as a rule, be determined directly, nor is it necessary, as they can be easily calculated as follows :—

(1) The composition of the dung from 100 lbs. of hay can be found from the composition of the food and the coefficients of digestibility ; and the T.F.V. can be calculated as before.

Total Fuel Value of the Dung.

Constituents indigestible.	Per cent.		Factor.		Fuel value.	T.F.V. (Kt.)
Oil	1·5	×	8·5	=	12·75	160·95
"Albuminoids" (proteins)	6·0	×	5·8	=	34·80	
Carbohydrates and Crude fibre . . .	27	×	4·2	=	113·40	

(2) It is shown (p. 172) that 0·343 parts of urea are formed from each part of protein digested. The fuel value of urea is 2·542 kt. per lb. The fuel value of the urea from 1 lb. of protein is, therefore, [2·542 × 0·343 =] 0·872 kt. ;

and the fuel value of the urea from 4 lbs. of protein digested is [0·872 × 4 =] 3·488 kt.

(3) Experiments in the respiration chamber show that 3·17 lbs. of methane are formed from each 100 lbs. of pure starch. The fuel value of methane is 13·34 kt. per lb. The fuel value of the methane from 1 lb. of starch is, therefore, [13·34 × 3·17 ÷ 100 =]·0·423 kt.; and the fuel value of the gases from 41 lbs. of digested carbohydrates is [0·423 × 41 =] 17·34 kt.

(4) The fuel values of the dung 160·95 kt., the urea from the digested protein 3·488 kt., and the gases from the digested carbohydrates 17·34 kt. are now to be added together and subtracted from the total fuel value of the food.

$$364{\cdot}43 - 181{\cdot}78 = 182{\cdot}65 \text{ kt.}$$

The *available* energy of the food is, therefore, 1·83 kt. per lb.

The fuel value of the urea from 1 lb. of protein is [2·542 × 0·343 =] 0·872 kt. The available energy of the protein is, therefore, [5·8 — 0·87 =] 4·93 kt. per lb.

The fuel value of the methane from 1 lb. of starch is [13·34 × 0·0317 =] 0·4229 kt. The available energy of the starch is, therefore, [4·1825 — 0·4229 =] 3·76 kt. per lb.

As there are no by-products from the fat, the available energy is the same as the total fuel value, viz. 8·5 kt. per lb.

By applying these factors to the digestible constituents, the same result as before is obtained more directly, thus—

Constituents digested.	Per cent.		Factor.		Available Energy. (Kt.)
Oil	1·0	×	8·5	=	8·50
Protein	4·0	×	4·63	=	19·52
Carbohydrates and Crude fibre . . .	41·0	×	3·76	=	154·16
					182·18

The available energy of the food is, therefore, 1·82 kt. per lb.

Loss of Heat.—In the case of non-pregnant animals in stationary condition, *i.e.* not growing, fattening, working, or producing milk, the heat or kinetic energy resulting from oxidation of the food is dissipated in several ways, viz. (1) in warming the ingesta and respired air; (2) by evaporation of water from the skin and lungs; (3) by radiation from the skin.

The amount of heat required to warm the ingesta (the food and water consumed) can be investigated from known data.

By definition (p. 119), 1 kt. is the amount of heat required to raise the temperature of 1000 lbs. of water 1° C; so 0·001 kt. is the amount required to raise the temperature of 1 lb. of water 1° C. Therefore—

$$H = 0{\cdot}001M(T_1 - T_2)$$

where H is the amount of heat (kt.) required, M is the mass (in pounds) of water consumed, T_1 is the temperature of the animal's body, and T_2 that of the water. Practically the same formula may be used for the dry matter of the food; but it must be multiplied by the specific heat (0·5) of the dry matter.

The temperature of the animal's body is practically constant. For farm animals it is about 100° to 104° F.—say 40° C. The temperature of the ingesta may be anything from less than 0° C. up to 20° C. or more.

Example.—Suppose an ox to consume 50 lbs. of roots at a temperature of 10° C., and that they contain 90 per cent. of water and 10 per cent. of dry matter, then—

$$H = 0{\cdot}001 \times 45 \times (40 - 10) = 1{\cdot}35 \text{ kt. for the water.}$$
$$H = 0{\cdot}001 \times 5 \times 0{\cdot}5(40 - 10) = 0{\cdot}075 \text{ ,, \quad ,, dry matter.}$$

i.e. 1·425 kt. is required to warm the whole of this ingesta to the temperature of the body.

If the available energy of the roots is about 0·29 kt. per lb., 4·9 lbs. would be used merely to warm the food to the temperature of the animal's body. Of this quantity, 4·66 lbs. would be required for the water and only 0·24 lb. for the dry matter. The loss of heat due to warming the ingesta, apart from water, is not, therefore, of much account.

The amount of heat lost by evaporation of water may be investigated in a similar manner. The latent heat of water at 40° C. is 580 units, *i.e.* to evaporate 1 lb. of water at that temperature, as much heat is required as would raise the temperature of 580 lbs. of water 1° C. = 0·58 kt. Therefore—

$$H = 0{\cdot}58M$$

where M is the mass (in pounds) of the water evaporated, and H is the heat required.

Example.—An ox consumed, daily, on the average—

26 lbs. hay containing 15% water = 3·9 lbs. water.
And 6½ gallons of water . . . = 65 "
Total water consumed . 68·9 "

The average daily droppings were—

48 lbs. dung containing 79·7% of water = 38·26 lbs. water.
14 lbs. urine " 88·0% " = 12·32 "
Total water excreted in liquid form . 50·58 "

The difference, [68·9 — 50·6 =] 18·3 lbs., is the average daily amount of water evaporated. The amount of heat consumed in this way is therefore—

$$18{\cdot}3 \times 0{\cdot}58 = 10{\cdot}614 \text{ kt.}$$

Assuming that the available energy of the hay was 1·83 kt. per lb., 5·8 lbs. of the food would be consumed in this way.

At higher temperatures, *e.g.* in very warm weather, a greater amount of water is evaporated and a larger quantity of food is used for the purpose.

The available energy of the food required for the maintenance of an ox (1000 lbs. live weight) in stationary condition is about 35 kt. per day. Allowing 2 kt. for warming the ingesta and 10 kt. for evaporation of water, there remains 23 kt. unaccounted for. A small portion of this is used for warming the respired air, and the remainder—over 60 per cent. of the whole[1]—is lost by radiation from the skin.

Theoretically, for any given animal, the loss of heat by

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[1] N.B.—This is merely a hypothetical case. The amount of heat actually radiated from the skin is variable but always large.

radiation is proportional to the difference between the temperature of the animal's body and that of the atmosphere to which it is exposed. For example, when the temperature is down to 0° C., the animal would lose twice as much heat in a given time as it would when the temperature is up to 20° C., because the difference, as compared with the temperature of the animal's body (40° C.), would be twice as great. There are, however, many other points to be taken into account, such as the condition of the animal's coat due to clipping, etc.; the effect of high winds which rapidly carry off the heat; warming and evaporation of water which falls upon the skin in wet weather, etc. The effects of all these variable conditions cannot be reduced to a formula; but they may be summed up in the statement that exposure involves greater loss of heat, and more food must be consumed to maintain the temperature of the body. If the available energy of the food is not sufficient to maintain the temperature, the tissues of the body are oxidised, and the animal loses weight. Conversely, a considerable saving of food may be effected by shelter and warmth.

Large animals require more food than small ones. An ox, for example, eats much more than a sheep or a pig in a given time. The larger animals evaporate more water, and lose more heat by radiation, than the smaller ones. The amount of food required, however, is not directly proportional to the size as measured by mass. An ox of 1600 lbs. live weight does not require twice as much food as one of 800 lbs. Under given conditions, the loss of heat by radiation is proportional to the extent of body surface exposed, and the surface does not vary directly as the mass (live weight).[1]

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[1] The bodies of farm animals, apart from the head and limbs, are approximately cylindrical. In the case of oxen, the length of the trunk or barrel is about 1½ times the diameter. The relation between surface and mass may, therefore, be illustrated by reference to the properties of a cylinder of water of similar dimensions. In such a cylinder, the ratio of surface to volume is inversely as the diameter, and the mass of water in it is proportional to the volume. In the units of the metric system (grams and cubic centimetres) the volume and mass of water are expressed by the same numbers. Thus it is found that when the mass

Kellner[1] describes investigations upon the bodies of dogs in which the following results were obtained:—

Body mass (kg.)	3·2	6·5	9·6	18·2	19·8	24·0	31·2
Body surface (sq. cm.) .	2423	3724	5286	7500	7662	8805	10750
Loss of heat (per kg.) .	88·1	66·1	65·2	46·2	45·9	40·9	36·6
Loss of heat (per sq. cm.)	1212	1153	1183	1097	1207	1112	1036

On comparison of the first and last columns it will be seen that when the mass is increased [31·2 ÷ 3·2 =] 9·75 times, the body surface is increased only [10750 ÷ 2423 =] 4·43 times, *i.e.* animals (dogs) of tenfold mass have only about 4·7 times the extent of body surface. It is in consequence of this that the loss of heat per unit of mass is much greater in the case of the smaller animals. The loss of heat per unit of surface is much alike in all cases. The larger animals, therefore, do not require so much food in proportion to their weight.

Maintenance.—It has been found that the daily food required by an ox of 1000 lbs. live weight yields about 35 kt. of available energy. If the amount required by animals of different sizes were directly proportional to the mass (live weight) then (35 ÷ 1000) would be the amount for an animal of 1 lb., and M(35 ÷ 1000) for one of M lbs. live weight. Actually, however, this is not so. An ox of 800 lbs. requires about 30 kt. and one of 1600 lbs. about 48 kt. per day. The simple formula above must, therefore, be amended. When the live weight (M) is less than 1000 lbs. something must be added to, and when it is more something must be deducted from, the proportional quantities.

In view of the fact that animals of tenfold mass have only

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of water is increased tenfold, the surface of the cylinder is increased only 4·6 times. Animals, of course, are not mathematical cylinders of water, and the analogy, if pressed, might prove misleading. Nevertheless, a very similar relation exists between their mass (live weight) and body surface, as shown in the text.

[1] "The Scientific Feeding of Animals."

about five times the radiating surface, and other facts of a similar kind, it seems probable that their food requirements will stand in a like relationship. In other words, when the mass is increased ten times, the food should be increased only about five times, and *vice versâ.* In that case ten animals, each of 100 lbs. live weight, would require twice as much food as one similar animal of 1000 lbs. live weight.

On this basis it is easy to construct a formula by which to calculate the food requirements of oxen of any given size (weight). The following[1] is, perhaps, the simplest mode of expression; and it corresponds with the available data regarding the maintenance requirements of oxen of different sizes.

$$\log E = 0{\cdot}7 \log M - 0{\cdot}556$$

E is the amount of available energy (kt.) of the food required, and M is the live weight (lbs.) of the animal.

The graph A (Fig. 8) was plotted from the values of E, calculated by the formula, for each 100 lbs., up to 2000 lbs. live weight. It shows the amount of food (kt. per head) required. B gives the same results expressed as kt. per 1000 lbs. live weight. The dotted line corresponds to the formula $35M \div 1000$, and shows how the curve A deviates from the line of strict proportion.

The formula based upon the requirements of oxen is not applicable to sheep, because in the case of the latter the radiation of heat is greatly diminished by their thick coats of

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[1] Assuming that the relation of M and E is that described in the text, we have the following corresponding values :—

$$\begin{array}{lccccc} M = & 1 & 10 & 100 & 1000 & 10{,}000 \\ E = & 0{\cdot}28 & 1{\cdot}4 & 7 & 35 & 175 \end{array}$$

or

$$E = \frac{0{\cdot}28M}{1} \quad \frac{0{\cdot}28M}{2} \quad \frac{0{\cdot}28M}{4} \quad \frac{0{\cdot}28M}{8} \quad \frac{0{\cdot}28M}{16}$$

Or if M = 10, this may be put as follows :—

$$E = \quad \frac{0{\cdot}28M}{2} \quad \frac{0{\cdot}28M^2}{2^2} \quad \frac{0{\cdot}28M^3}{2^3} \quad \frac{0{\cdot}28M^4}{2^4}$$

$$\begin{aligned} \therefore \log E &= \log M + \log 0{\cdot}28 - \log M \times \log 2 \\ &= \log M + \bar{1}{\cdot}4472 \quad - \log M \times 0{\cdot}301 \\ &= \log M\,(1 - 0{\cdot}301) + (0{\cdot}4472 - 1) \\ &= 0{\cdot}699 \log M - 0{\cdot}5528 \end{aligned}$$

wool. According to the above formula an animal of 100 lbs. live weight requires about 7 kt. for simple maintenance, but

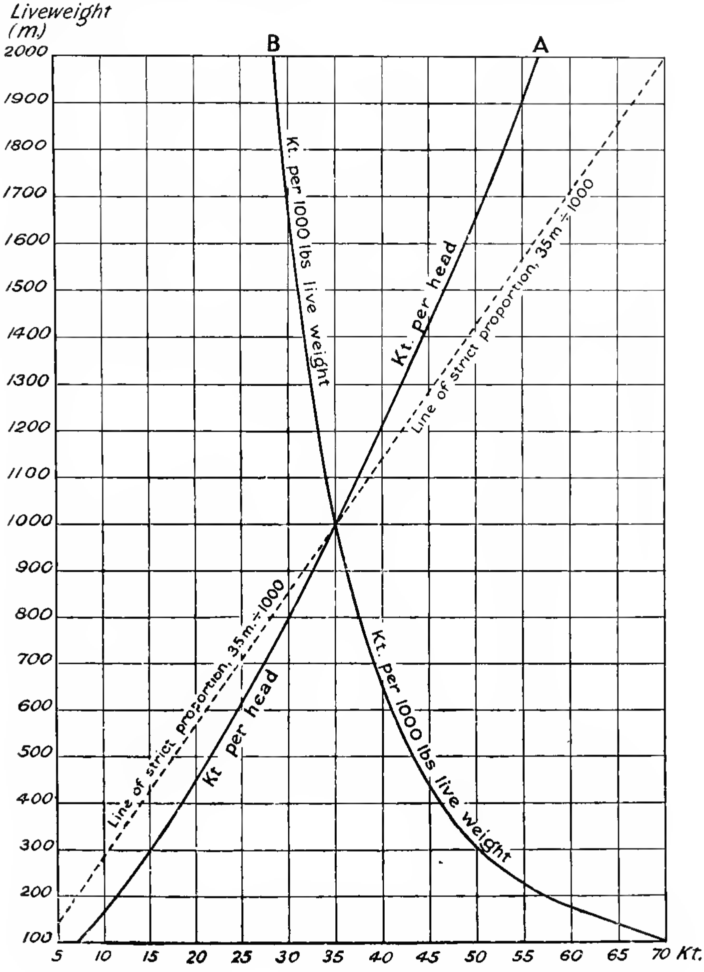

FIG. 8.

experience shows that a sheep of that size requires only from 4 to 4·5 kt., according to the texture of their wool. Taking the former figure as the fundamental unit, and assuming the same relative variation as before, the formula to be used in calculating maintenance rations for sheep of different size would be—

$$\log E = 0{\cdot}7 \log M - 0{\cdot}8$$

Respiration Chamber Experiments.—Much valuable information regarding the quantities of food required by animals under different conditions was derived from the older experiments. In these the plan generally followed was the simple and obvious one of feeding the animals on food of known composition. The food was, of course, accurately weighed, and the quantities were varied until the desired effect was produced according to the purpose of the experiment. The effects were determined by weighing the animals from time to time.

The knowledge so obtained has been greatly extended and increased by recent experiments of a more elaborate character. These were carried out in the respiration chambers previously referred to, the object being to determine the actual amounts of carbon and hydrogen oxidised in the animal's body, and the amount of energy (heat) produced.

Various forms of apparatus have been used for the purpose. That of Pettenkofer, shown in the illustration[1] (Fig. 9), consists essentially of a cubic iron box, about eight feet each way. The plates of which it was constructed were riveted together like those of a boiler, and made perfectly air-tight.

When the subject of the experiment was introduced into the apparatus, a steady current of air was drawn through by means of pumping machinery. The composition of the air entering and leaving the chamber was determined by analysis, and the quantity was accurately measured by large meters designed for the purpose. In this way accurate information was obtained regarding the amounts of oxygen consumed, of carbon dioxide, water, etc., produced, and, inferentially, of the amounts of carbon, hydrogen, etc., stored in the body during

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[1] Bulletin No. 21, Office of Experiment Stations, U.S. Department of Agriculture.

the time of the experiment. The digestibility of the food can, of course, be determined at the same time.

In some experiments, *e.g.* those of Rosenthal, Atwater, and others, the chamber was fitted with apparatus for recording minute changes of temperature in order to determine the amounts of energy produced by the oxidation. In that case the chamber serves as a kind of calorimeter for living subjects, and it is often called a respiration calorimeter.

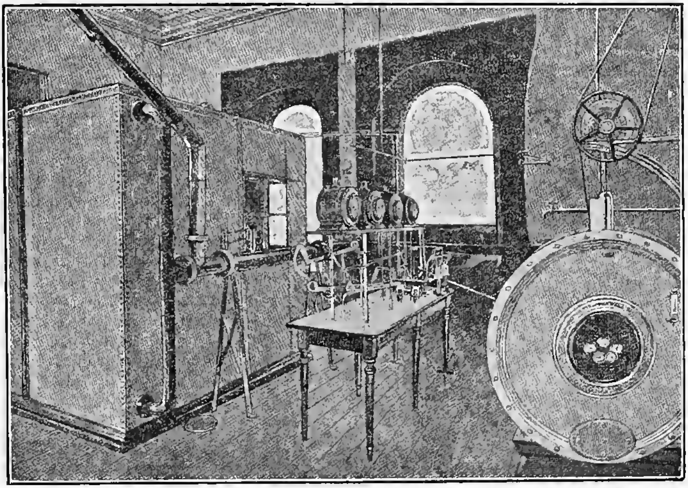

FIG. 9.—Pettenkofer's Respiration Apparatus.

The more important results of the experiments have already been described, but they may be briefly summarised as follows :—

(1) For simple maintenance of the animals without gain or loss of weight, the daily quantities of food must be such as to produce the following amounts of available energy :—

For oxen and horses, 35 kt. per 1000 lbs. live weight.
„ sheep, 40 kt. per 1000 lbs. live weight.

(2) The available energy of the digested fats is the same as the total fuel value (8·5 to 9·4 kt. per lb.), *i.e.* it is 100 per

cent. The available energy of the digested protein is only about 85 per cent. of the total fuel value (4·93 kt. per lb.); and that of the digested carbohydrates and fibre about 90 per cent. (3·76 kt. per lb.).

The total fuel values and available energy of various foods will be found, with other data, in the tables at the end of the next chapter.

The number of kilo-pound-units of available energy, per unit of mass (1 lb.), may be called the "static" or "thermic value" of the food. This energy is available only to maintain the animal in stationary condition, *i.e.* without gain or loss of weight. It is not all available for other purposes. The reason for insisting upon this will be made plain in later chapters.

Protein.—The static values form a useful basis for comparison of the foods used for the maintenance of animals, but they afford no information regarding the amount of protein required. It was shown (p. 111) that under all conditions animals require certain amounts of that constituent to repair the waste of the nitrogenous tissues; and if they do not get enough, they die of nitrogen starvation.

Theoretically the amount of digestible protein required for the maintenance of an animal is equal to the amount oxidised[1] in a given time. This amount may be estimated, as previously shown, from the amount of nitrogen in the urine which contains all the nitrogenous products of metabolism.

The amount of protein oxidised, however, varies under different circumstances. It depends partly upon the amount of digestible protein and other nitrogenous compounds (p. 112) in the food, and partly upon the degree of protection from oxidation afforded by the presence of larger or smaller quantities of non-nitrogenous nutrients. In order to ascertain the minimum amount of protein required, it is necessary to investigate how much is oxidised when the animal is fasting. The following example will make this clear.

[1] This is not always a true measure of the amount of protein which should be given in the food. In some cases, if the protein were limited to this amount, the digestibility of the other constituents would be diminished.

Oxen were the subject of the experiment, and the figures have been adjusted to correspond to 1000 lbs. live weight. It was found that—

(1) When fasting absolutely, the animals lost weight at first at the rate of about 3 lbs. per day, and the nitrogen in the urine corresponded to about 1 lb. of protein in twenty-four hours. Obviously such an experiment cannot be continued for many days, as the animals would soon die.

(2) When the animals were fed on a ration of fat and carbohydrates having thermic value of not less than 35 kt. per day, *i.e.* enough to supply all the energy required for maintenance, the loss of weight was greatly diminished, and the nitrogen in the urine corresponded to only about 0·3 lb. of protein in twenty-four hours.

N.B.—There was no nitrogenous matter in the food.

(3) When small quantities of protein were added to the above ration, there was no increase in the amount of nitrogen in the urine, and the loss of weight was practically arrested.

(4) When the quantity of digestible protein, added to the non-nitrogenous ration, exceeded about ½ lb. per day, the nitrogen in the urine was increased by an amount corresponding to the excess of protein; but there was no increase in the weight of the animal when the static value of the ration as a whole did not exceed the stipulated amount, 35 kt. per day.

(5) When the animals were fed on mixed ordinary rations, the amount of nitrogen in the urine corresponded to from 1 lb. to 1½ lbs. per day.

(6) When the food contained more than ½ lb. of digestible protein and the thermic value exceeded 35 kt., the animal gained weight.

The inference drawn from these data is that, for the maintenance of oxen without gain or loss of weight, the food must not only have a thermic value of 35 kt., but also it must contain at least ½ lb. of digestible protein per 1000 lbs. live weight per day.

The results of many different experiments and observations lend great weight to this conclusion; but they also tend to show that, in general, it is not expedient to restrict the supply of protein to this theoretical minimum. In practice, it is usual to feed larger quantities of protein to store animals, and the following arguments have been adduced in support of the custom.

It is necessary to make allowance for the differences between individual animals and for the variation in the character and quality of the foods. The figure given above no doubt represents a close approximation to the truth, but it is not a mathematical certainty.

The digestibility of the carbohydrates is reduced if the proportion of protein is too small, especially if the ration includes a large bulk of difficultly digestible materials. This has been attributed to the fact that the digestive enzymes, which are nitrogenous compounds, are formed from the protein, and that larger quantities of the ferments are required for the digestion of such materials.

Each kind of animal requires a particular combination of the amino-groups derived from the protein, to form its tissues, and any groups which are not required are split off and oxidised. As we have very little information regarding the proximate composition of the different proteins of the foods and practically none regarding the particular groups required by the animals, it is advisable to make allowance for possible waste in this way.

The health of the animals is improved when they get more than the theoretical minimum quantity of protein. This has been denied on the strength of certain investigations carried on for short periods; but it has been found that when cattle are kept for many months on very low nitrogenous rations they lose their coats and exhibit a tendency to contract disease and ailments of various kinds. On the other hand, when they receive larger quantities of nitrogenous matter, their respiration is quickened, circulation becomes more vigorous, and body temperature a little higher.

Deficiency of protein means starvation. A moderate excess over and above the theoretical minimum is certainly harmless and is probably beneficial.

For these reasons, therefore, it is customary to allow the following quantities of digestible protein in the maintenance rations of animals.[1]

For oxen and horses, about ¾ lb. per 1000 lbs. live weight, per day; and for sheep about 1¼ lbs. per 1000 lbs. live weight per day.

Sheep require larger quantities of protein than cattle or horses in proportion to their weight, because of the production of the wool. Wool is a nitrogenous substance formed from the protein of the food, and its growth is not arrested even when the animals are in a state of practical starvation.

Feeding Standards.—The attempt to reduce the food requirements of animals to formulæ, such as that given on p. 128, is something of an innovation. The older and generally accepted method is to state the amounts of digestible nutrients required by animals per 1000 lbs. live weight irrespective of their actual size. Such a statement is called a "feeding standard." For example, according to Wolff, the feeding standard for the maintenance of oxen is as follows:—

DIGESTIBLE NUTRIENTS REQUIRED PER 1000 LBS. LIVE WEIGHT PER DAY.

Protein. lbs.	Fat. lbs.	Carbohydrates. lbs.	Total organic matter. lbs.
0·75	0·15	8·0	17·5

The statement that oxen of 1000 lbs. live weight require for maintenance a daily quantity of food which yields 35 kt. of available energy and a certain amount of protein, is also a feeding standard. In fact, it is the same feeding standard expressed in different terms. This may be proved in either of two ways as follows:—

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[1] N.B.—The digestible protein of the maintenance ration undergoes oxidation like other constituents of the food, and the heat produced helps to maintain the temperature of the animal's body. A part of the 35 kt., or whatever the amount may be that is required for maintenance, is derived from the oxidation of the protein; the latter is not, therefore, an addition, but is included in the former. In calculating rations it is important to see that the amount of food which gives the required thermic value also contains the required amount of digestible protein.

(1) Multiply the quantities of the several constituents by their thermic values, and the sum of the products will be found to amount to 35 kt. Thus—

Protein	0·75 × 4·93 =	3·69
Fat	0·15 × 8·50 =	1·27
Carbohydrates	8·00 × 3·76 =	30·08
		35·04 kt.

(2) By the reverse method—

Deduct the thermic energy of the protein from the total, 35 — (0·75 × 4·93) = 31·31 kt.

Divide the balance by the available energy of the starch, 31·31 ÷ 3·76 = 8·33 lbs. starch.

The feeding standard in terms of nutrients, therefore, is 0·75 lb. of protein and 8·33 lbs. of carbohydrates, or 8 lbs. of carbohydrates and 0·15 lb. of fat.

It is a matter of indifference in which of the two forms the feeding standard is expressed. In the author's opinion it is more convenient to state it in terms of protein and of available thermic energy instead of pounds non-nitrogenous nutrients; for, after all, the latter merely represents so much energy.

The method of stating the quantities as per 1000 lbs. live weight is open to more serious objection; for it is usually held to imply that the quantities required by animals (of the same kind and condition) of any other weight can be calculated by rule of three. But it has been shown (p. 127) that the requirements of the animals are not directly proportional to their mass. The rule of three cannot, therefore, be used, and the feeding standards cannot be properly applied to animals that are not of the size assumed.

For instance, the total weight of a group of five oxen having an average live weight of 1600 lbs. per head would be exactly the same as that of a group of ten having an average live weight of 800 lbs. per head. According to the customary methods of using feeding standards, the daily rations should be exactly the same for each of the groups, viz. about 153 lbs. of hay. This quantity would, however, be too little for the smaller animals and too much for the larger ones. The rations calculated by means of the formula (p. 128) correspond to 164 lbs. of hay for the former and 133 lbs. for the latter—a difference of 31 lbs.

When the live weight of the animals does not vary more than about 10 per cent. from that on which the feeding standard is based, the error would be, perhaps, negligible; but when the variation amounts to 50 or 100 per cent., *i.e.* when the actual live weight of the animals is only half or is double that assumed, the error would be more considerable.

In order to obtain accurate results, it would be necessary, in the case of oxen, to have a different feeding standard for each 100 lbs. or so of live weight from about 500 lbs. up to 2000 lbs. Such multiple feeding standards are never given for oxen, but they are generally considered necessary in other cases. Thus, different feeding standards are given for pigs of 50 lbs., 100 lbs., and so on, up to 300 lbs., live weight. The quantities of nutrients are, however, usually stated as per 1000 lbs. live weight in each case. For example, if the feeding standard for pigs of 50 lbs. live weight be 6·6 lbs. of protein, and 30 lbs. of non-nitrogenous nutrients per 1000 lbs. live weight, then the quantities per head would be 0·33 lb. of protein and 1·5 lbs. of non-nitrogenous nutrients. For ten such pigs the quantities would be 3·3 lbs. of the former and 15 lbs. of the latter. It is assumed, of course, that all the ten pigs are approximately of the same weight. If they were not, the feeding standard would not be applicable even though the sum of the live weights amounted to 1000 lbs.

The deductions from experiments on fattening animals, milk cows, and working horses, have also been expressed in the same form. Such feeding standards include the amounts of nutrients required for the simple maintenance of the animals as well as those required specially for fattening, milk production, and work. They are, in fact, theoretically, the sum of the two quantities. They are, therefore, subject to the same limitations as the feeding standards for maintenance, and there are other circumstances, peculiar to each case, which render them even more unreliable. These circumstances will be dealt with more particularly as they arise, but the more important difficulties may be briefly summarised beforehand.

For a variety of reasons the foods used specially for fattening, work, and milk production, *i.e.* as additions to the maintenance rations, are generally of a different—more concentrated and more expensive—character than those used merely for maintenance; and the nutrients of two such different classes of feeding stuffs cannot properly be added together without correction, for they have very different values. If the necessary corrections are made, the process must be reversed when the actual rations are deduced from the feeding standards.

The amounts of nutrients required for maintenance of each kind of animal depend upon the size; the amounts required for other purposes depend upon the amounts of work, milk, or increase produced. There are, therefore, two factors to be considered—the food for maintenance and the additional food for special purposes; and in each case these two factors vary independently of the other. It is generally advisable, therefore, to keep the two things theoretically distinct, and to calculate the portions of the rations for each purpose separately.

The feeding standards are purely empirical; they generally represent a compromise, and can, at best, only give approximate results. The system is, however, in general use, not only in this country, but also throughout Europe and in America. The feeding standards commonly employed are, therefore, given for comparison with the formulæ.

It will be found that, in most cases, the data correspond with those calculated by means of the formulæ given in this and later chapters, so far as the conditions assumed by the feeding standard are strictly adhered to. Discrepancies of more or less considerable importance, which arise when the circumstances are varied, may be attributed, in most cases, to the fact that the feeding standards are not applicable in the new conditions.

The maintenance requirements of oxen, calculated by the formula in terms of available energy, may be translated into the corresponding amounts of nutrients as follows[1] :—

$$\log E = 0{\cdot}7 \log M - 0{\cdot}556$$

$$P = \frac{E}{49{\cdot}3};\ C = \frac{E}{4{\cdot}18}$$

P is the amount (lbs.) of protein and C is the amount (lbs.) of non-nitrogenous nutrients reckoned as starch. A certain amount of the latter may, of course, be given in the form of fat. (See also note at end of chapter.)

Example.—In the case of oxen of 1000 lbs. live weight, E = 35 kt. Therefore—

$$P = \frac{35}{49{\cdot}3} = 0{\cdot}71\,;\ C = \frac{35}{4{\cdot}18} = 8{\cdot}37$$

In the case of sheep the formulæ would be as follows[2] :—

$$\log E = 0{\cdot}7 \log M - 0{\cdot}8$$

$$P = \frac{E}{39{\cdot}44};\ C = \frac{E}{4{\cdot}3}$$

Rations.—Rations for maintenance may be determined from the feeding standards, or from the results calculated by means of the formulæ, provided the composition of the feeding stuffs are known. If the available energy of the food is known, it is not necessary to translate it into terms of non-nitrogenous nutrients.

On reference to the tables (p. 167) it will be seen that average meadow hay yields 1·83 kt. of available thermic energy per lb., so [35 ÷ 1·83 =] 19·1 lbs. will be required for the maintenance of oxen of 1000 lbs. live weight; and as such hay contains 21·8 lbs. of protein per 1000 kt. of energy,

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[1] For reasons given in the text, not less than 10 per cent. of the total available energy must be derived from protein, which yields 4·93 kt. per lb. The remaining $\frac{9}{10}$ths, reckoned as starch, yields 3·76 kt. per lb. Therefore

$$P = \frac{E}{10} \times \frac{1}{4{\cdot}93} = \frac{E}{49{\cdot}3} \qquad C = \tfrac{9}{10}E \times \frac{1}{3{\cdot}76} = \frac{E}{4{\cdot}18}$$

[2] $$P = \tfrac{1}{8}E \times \frac{1}{4{\cdot}93} = \frac{E}{39{\cdot}44} \qquad C = \tfrac{7}{8}E \times \frac{1}{3{\cdot}76} = \frac{E}{4{\cdot}3}$$

there will be [0·0218 × 35 =] 0·76 lb. to 35 kt., *i.e.* in 19 lbs. of hay. As 19 lbs. of hay yields a sufficient amount of available energy, and contains rather more than the minimum amount of protein required, it should form an adequate ration for the maintenance of oxen of the size assumed.

It will be seen on reference to the tables (p. 166) that the T.F.V. of roots and succulent fodders, owing to the large amount of water they contain, is much less than that of drier materials. In most of the latter, it ranges from about 3½ to 4 kt. per lb., but in those which contain much oil it is higher.

The thermic values of the foods do not exhibit the same degree of uniformity, chiefly because of the difference in the digestibility of the constituents, especially the cellulose. For example, the T.F.V. of sawdust is about 4 kt. per lb., but of this total only about 0·6 kt. is available.[1] In cakes, cereal grains, and other concentrated foods of which the coefficients of digestibility are high, the thermic value is from 70 to 80 per cent. of the T.F.V. Rape cake and undecorticated cotton cake are conspicuous exceptions to this rule. Even in offals, *e.g.* sharps, bran, brewer's grains, etc., the thermic values are from 60 to 70 per cent of the T.F.V. In hays, straws, and coarse fodders generally, the thermic value is generally less than half the T.F.V.

Cakes and grains are not much used for maintenance rations. They are at once too concentrated and too expensive. Ruminants, and also horses, require a certain amount of the coarser fodders—hay, straw, etc.—and, in proportion to the amount of thermic energy which the animals derive from them, these foods are much cheaper than cakes and grains.

The cost of various foods per 1000 kilo-pound-units of static or thermic energy is given in the eleventh column of the tables. Compared on this basis it appears that the roots are the cheapest at the prices assumed. They cost from about 14*s*. to 16*s*. per 1000 kt. Sugar beet appear to be even cheaper, but perhaps the price assumed is too low. A

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[1] Owing to its effect on the digestibility of other foods when sawdust is mixed with them, the actual value of the latter is less than 0.

certain pecuniary economy can therefore be effected by using considerable quantities of roots, but excessive amounts should be avoided. Owing to their watery character, deficiency in protein and other characteristics, it is probably not profitable, under ordinary circumstances, to give more than about 50 or 60 lbs. per 1000 lbs. live weight per day. Many men of large experience prefer to give even less.

The cost of the thermic energy in hay and cereal straws works out to about 15*s.* to 17*s.* per 1000 kt. The digestibility of both substances is of course taken into account in this estimate, but the amount of protein they contain is not. When the latter is considered, it will be found that, at the prices mentioned, hay is much the cheaper of the two. Any deficiency of protein must be made up from other and more expensive foods, and the deficiency would be much greater in a ration consisting largely of straw than in one of hay. Straws and the inferior qualities of hay are not suitable for horses though they may profitably enter into the rations of ruminants.

Coarse fodders, such as hay and straw, are not suitable for pigs, and even the maintenance rations[1] for these animals must, therefore, consist largely of the finer meals and offals. Several foods, *e.g.* rape cake, locust beans, brewer's grains, sharps, bran, pollards, rice meal, and maize, can be obtained at prices which work out at about £1 per 1000 kt., and some of these are suitable. All the other foods, except wet brewer's grains, are more expensive. Barley costs about 26*s.* and potatoes about 19*s.* per 1000 kt., the latter being charged at only 30*s.* per ton. According to the figures given in the tables, brewer's grains in the wet condition are cheaper even than roots; they are also relatively rich in protein, but are not suitable for maintenance rations, and there are other objections to their use (p. 281).

Too much importance should not be attached to these conclusions. The composition of the foods is subject to considerable variation, and market prices fluctuate from day to

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[1] Pigs are not usually kept in store condition, but it will be shown later that every animal must receive a sufficient maintenance ration, whether it gets anything additional for fattening, etc., or not.

day; and it is upon these data that the estimates are based. For the common articles of commerce—cakes, grain meals, etc.—the comparison is perhaps more reliable than in the case of home-grown products such as hay and roots. The former are more constant in composition and the actual prices at which they are sold and bought are easily ascertained from the market reports published in the agricultural and daily papers. The prices of hay, straw, and sometimes even of roots can be ascertained in a similar manner, but this probably does not give a fair basis of comparison. The cost of production, or "consuming value," of hay on the farm is usually much less than that of the same product in the London or Manchester market, and it is very difficult to decide exactly what prices should be assigned to such products. Potatoes, for instance, are quoted in the papers at 90*s.* to 100*s.* per ton, but the chats which are given to the pigs should certainly be priced at a much lower figure.

Notwithstanding all this, however, the broad fact remains that the most economical *maintenance* rations for ruminants and horses are those which consist most largely of roots, hay, and straw. These foods should therefore be used to the largest extent that is compatible with the conditions as regards the amounts of protein and thermic energy required for simple maintenance of the animals. In later chapters it will be shown that it is not economical, but the reverse, to use larger quantities of the coarse fodders.

These inferences are entirely consistent with the universal practice, based on experience, of farmers, and the fact may be regarded as strong confirmation of the truth of the theories from which they are drawn. It was, of course, unnecessary to prove what is accepted, but a knowledge of the theoretical aspects of the subject gives the farmer a valuable means of control in these and in more complex cases; and further arguments will be based on the conclusions thus shown to be sound.

NOTE.—If 9 lbs. be the amount of total digestible nutrients required by oxen of 1000 lbs. live weight, the requirements of those of any other size can be calculated directly by the formula: $\log N = 0{\cdot}7 \log M - 1{\cdot}145$. N is the amount (lbs.) of digestible nutrients.

CHAPTER X

DYNAMICS

Energy.—Work has been defined as overcoming resistance, and energy as that which, when properly applied, can do work, *i.e.* can overcome resistance. All work, therefore, involves expenditure of energy. In an ordinary engine, the energy (heat) is derived from the combustion of fuel. The engine itself is merely a mechanical device for applying this energy so as to overcome some kind of resistance.

Animals also can do work, *i.e.* they can apply energy so as to overcome resistance. In this case, the energy is derived from the oxidation of food. Physiologically, the process may be an indirect one. The energy may possibly be derived, proximately, from the oxidation of the tissues of the animal's body; these would be again restored from the materials of the food, so that, in any case, the energy is derived ultimately from the food.

It was shown in the previous chapter that the energy derived from the food required for the maintenance of the animal is dissipated in several ways. It cannot, therefore, be used to do work. If any part of it is used to do work[1] there will be a corresponding deficiency of energy required to maintain the temperature of the animal's body and for other purposes previously mentioned; in that case, some of the tissues will be oxidised (p. 110), and the animal will lose weight. If, therefore, an animal is required to do work, it must receive additional food over and above what is

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[1] This refers only to external work. The distinction between internal and external work is fully explained later on in this chapter (p. 154).

required for maintenance. Two questions arise in this connection, viz. (1) the kind, and (2) the quantity of the food that must be added to the maintenance ration when an animal does work.

As regards the former, Liebig argued that since animal work is done by the contraction and relaxation of the muscles, it must involve the deterioration of the muscular (nitrogenous) tissues of the body. These tissues can only be restored from the nitrogenous matter of the food, and he concluded, therefore, that the additions to the maintenance rations should consist mainly, if not wholly, of nitrogenous matter. It is true that animal work is done by contraction and relaxation of the muscles; but it does not follow that the energy which causes them to contract and relax is of necessity derived from the oxidation of their substance. The work of an engine is done by the thrust of the piston; but the energy which causes the thrust is derived from the combustion of fuel, not from the oxidation of the piston itself or of the cylinder in which it acts.

At any rate, Liebig's theory is untenable. The experiments of Voit and Pettenkofer[1]—and they have been confirmed by many others—clearly show that the amount of nitrogenous matter is practically the same when the animal does work as when it is resting. On the other hand, larger quantities of

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[1] The following results were obtained in experiments on a man in the respiration chamber. In each case the figures refer to periods of twenty-four hours.

	Nitrogen in urine.	Carbon dioxide exhaled.	Water.		Oxygen absorbed.
			In urine.	Evaporated.	
	Grams.	Grams.	Grams.	Grams.	Grams.
I. Fasting—					
At rest .	12·4	716	1006	821	762
At work . .	12·3	1187	746	1777	1072
II. On average diet—					
At rest . .	17·0	928	1218	931	832
At work . .	17·3	1209	1155	1727	981

oxgyen are absorbed, and more carbon dioxide and water are given off. It is impossible, therefore, to resist the conclusion that the energy for the performance of animal work is derived mainly, if not entirely, from the oxidation of the non-nitrogenous matter.

It is clear, then, that when animals do work, the available energy of the rations must be increased by additions of digestible fat and carbohydrates. There is no dissent from this proposition. It is unanimously agreed to by theorists and by practical men alike.

It has also been inferred that it is unnecessary to increase the amount of nitrogenous matter of the food beyond what is required for the maintenance of the animal when at rest. It must be recognised, however, that all animals, when put to hard work, exhibit a strong desire for more nitrogenous foods. We should not perhaps be justified in regarding their desires as an indication of their requirements, but it is found that such food markedly increases their capacity for work.

It will be shown presently that the amount of additional food required for work is large. In some cases it is greater than the quantity required for the maintenance of the animal when at rest. When large amounts of carbohydrates are added to or included in the ration, the amount of nitrogenous matter must be correspondingly increased (p. 106) to enable the animal to digest it properly.

The excess of protein, beyond what is required for the maintenance of the animal, is rapidly resolved into amino-compounds; and it is known that these substances when directly ingested have a powerful stimulating effect. The animal is thus induced to put forth greater effort and so to utilise the potential energy of the additional food.

It is doubtful whether these considerations can be regarded as affording an adequate explanation of the beneficial effects of increasing the amount of protein as well as of the fat and carbohydrates in the food of animals when they do work. Probably something more remains to be discovered. Chittenden indeed has questioned the fact. He maintained that excess of protein was not only unnecessary, but might even prove injurious to the health of the animals. As regards the latter point his apprehensions have proved to be unfounded; and though he adduced weighty experimental evidence in favour of the former, his views have not prevailed. Almost every recognised authority now recommends that the amount of protein in the maintenance ration should be increased when the animal is put to work.

Work.—The amount of additional food should be proportional to the work done. In order to investigate this question, it is necessary to select some standard for the measurement of work. The force of gravity is universally adopted for this purpose, and work is measured in terms of the resistance overcome. The amount of this resistance at any one place is proportional to the mass of the substance raised; and, for the present, the variation from place to place may be disregarded.

In English standards the unit of work is a foot-pound, *i.e.* a mass of one pound raised one foot high. Obviously, double the amount of work (2 units) is done when two such masses are raised one foot, or when a mass of one pound is raised two feet high. In short, the mass (in pounds) multiplied by the height (in feet) through which it is raised gives the number of units of work done. All work, whatever the nature of the resistance overcome, is measured in the same units (foot-pounds).

The energy expended in doing work is not anihilated, but merely transformed. It all appears ultimately in the form of heat. Some of the energy may be converted temporarily into the potential form; but when it is reconverted into the kinetic form, this also appears as heat. A very definite relationship between work and energy has thus been established. It was shown by Joule that when all the potential energy represented by 772 foot-pounds of work is converted into the kinetic form of heat, it will raise the temperature of one pound of water 1° F. That is what is meant when it is said that 772 foot-pounds of work is the mechanical equivalent of heat.

On the Centigrade scale, the degrees are 1·8 times larger than those of Fahrenheit's thermometer, so the energy of $772 \times 1{\cdot}8 = 1389{\cdot}6$ foot-pounds of work will raise the temperature of 1 lb. of water 1° C. Therefore, 1,389,600 foot-pounds of work = 1 kt.

Now, although the whole of the work can be obtained as heat, the converse is not true; the whole of the energy cannot be obtained as work. In the case of steam engines there is great loss of energy in the form of heat radiated from the boilers, and there is a certain amount of internal work of the machine itself due to the friction of the working parts, and so on. At best, steam engines do not give out as work more than about one-seventh part of the energy produced by combustion of the fuel.

Animals are much more economical—not necessarily in the pecuniary sense—in this respect. The temperature of their bodies is much lower than that of steam boilers, and they do not lose so much heat by radiation. What they do lose in this way is provided for in the maintenance rations. There is practically no internal friction, but there is a considerable increase in the internal work of circulation, etc., and the amount of water evaporated is much greater when the animal does work (p. 144).

Numerous experiments show that, under favourable conditions, animals can give out as work about one-third of the total available energy[1] of the food added to a sufficient maintenance ration. That is to say, that for each kilo-pound-unit of such energy in this added food, the animal can produce about [$1{,}389{,}600 \div 3 =$] 463,200 foot-pounds of work. Expressed as a formula, this would read—

$$W = 0{\cdot}4632D \text{ ; or } D = 2{\cdot}16W$$

where D is the amount (kt.) of dynamic energy in the food, and W is the amount (in million foot-pounds) of work.

The "power" of a machine or of an animal is measured by the amount of work it can do in a given time. The engineers' unit of 550 foot-pounds per second is called a "horse-power," because it was based on an estimate of the supposed capacity

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[1] Energy available for work (cf. p. 156).

of horses. It will presently be shown that this is a very variable quantity; but assuming that an animal did work at that rate, the amount of food required to provide the energy can be calculated from the data given, *i.e.* by the formula.

The normal day's work for a horse is 8 hours = 28,800 seconds; and at 550 foot-pounds in each second, the total amount of work done would be 15·84 million foot-pounds. Applying the formula $D = 2{\cdot}16W$, we have [$15{\cdot}84 \times 2{\cdot}16 =$] 34·21 kt. as the amount of dynamic energy to be supplied in the food. If the animal does not consume enough food to supply that amount of energy in addition to a sufficient maintenance ration, it cannot work for eight hours at the rate assumed without loss of weight.

Of course it is not usually possible to apply the formula to animal work in this simple manner, because in ordinary practice it is extremely difficult to estimate, with any degree of accuracy, the amount of work done. We are, therefore, compelled to revert to such vague, empirical standards as light, medium, and heavy work.

The total amount of work done in any case is expressed by the formula—

$$W = P \times V \times T$$

where W is the work (in foot-pounds), P the effort (in pounds), V the velocity (in feet per second), and T the time (in seconds) occupied; PV is, of course, the rate (in foot-pounds per second) at which the work is done, *i.e.* the total work done in 1 second. The following examples will make this plain:—

P Effort.	V Velocity.	T Time.	PV Rate.	PVT Total work.
Lbs.	Ft. per sec.	Sec.	Ft.-lbs. per sec.	Ft.-lbs.
50	5	32,400	250	8,100,000
100	3	28,800	300	8,640,000
200	2	25,200	400	10,080,000

When the work is done wholly against gravity, the effort, P, is represented simply by the weight (in pounds) of the substance raised. In many parts of Canada and elsewhere the waggons commonly used are made with a detachable box, and the barns are fitted with pulleys by means of which it can be raised by horse-power in order to save the labour of pitching up the sheaves when the grain is brought in. This kind of arrangement is roughly indicated in the diagram. If we disregard for the moment questions of leverage and the friction of the pulleys, it is clear that the tension of the rope, and therefore the pressure on the horse's collar, is equal to the weight of the box and contents. This pressure, called the draught, is expressed in pounds weight. If the animal were continuously engaged in labour of this kind for some time, it would be easy to apply the formula given above.

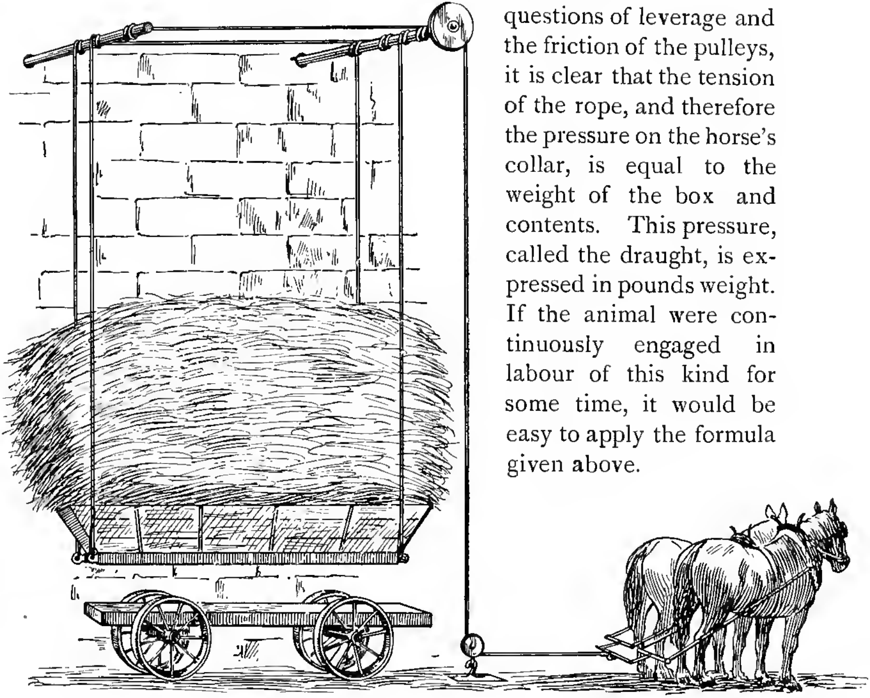


FIG. 10.

When the work is not done against gravity, but consists in hauling a cart along the level, the draught is much less in proportion to the mass of substance moved. In the case of a properly lubricated tramway car on a well-laid, level track it is very small. It arises chiefly from the friction of the wheels, which increases with the load, and the resistance of the air. In the case of an ordinary cart or waggon on a rough road, or in soft clay soil, it is more considerable. In any case it can be measured and expressed in pounds weight; but it must be noted that the draught is the pressure on the collar, not the mass of substance moved, except when the work is done wholly against gravity.

When an unharnessed horse walks or runs along the level there is no draught and no load, yet it does work; and if it continue all day, the work will amount to many foot-pounds. In this case the effort, P, is represented by the work of moving the animal's body through space. This may be put at about one-twentieth of the weight of the animal. Thus in the case of an unharnessed horse 1000 lbs. live weight, trotting at 7 miles per hour for 1 hour, the work would amount to 1·848 million foot-pounds, and at 10 miles per hour it would be 2·64 million foot-pounds.

When the animal carries a load on its back, this must be added to the weight of the animal. For example, suppose the weight of the saddle and rider were together equal to 200 lbs., the total effort would be equivalent to a draught of 60 lbs., whereas when the animal goes without any load, the effort is only equivalent to a draught of 50 lbs. In short, in the case of an animal without any load the effort, P, is $\frac{M}{20}$, and with a load it is $\frac{M+L}{20}$, where M is the live weight (in pounds) of the animal, and L is the weight (in pounds) of the load.

The three graphs drawn in the diagram (Fig. 11) show, respectively, the amount of work done in 1 hour by a horse of 1000 lbs. live weight, (*a*) when going at different speeds without any load or draught, (*b*) when carrying different loads on its back at a constant speed of 5 feet per second (3·4 miles per hour), (*c*) when going against different draughts at the same constant speed (3·4 miles per hour). The three graphs show the effect, on the total work done, of the given increments of speed, load, and draught respectively; but, of course, if the horse were of a different size or if different increments were assumed, the graphs would not bear the same relation to each other.

In the cases previously considered, it has been assumed

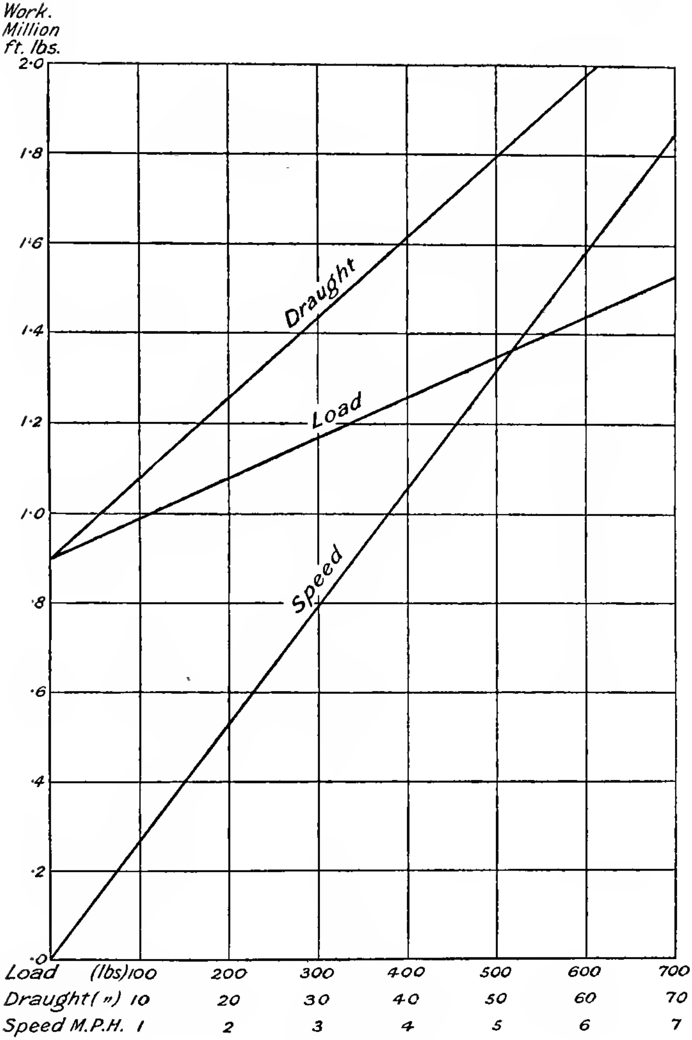
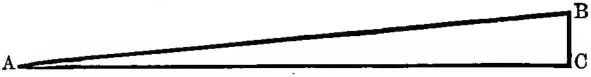


FIG. 11.

that the work was done either wholly against gravity or wholly on the level. The work done in hauling a laden cart uphill may be regarded as done partly on the level and partly against gravity, and the question can be investigated by considering the two parts separately. The following example will serve to illustrate the method.



Let the hill, AB, be 1 mile [= 5280 feet] long, and the gradient 1 in 10, *i.e.* the vertical component BC is 528 feet, and the horizontal—

$$AC = \sqrt{(AB)^2 - (BC)^2} = 5253{\cdot}5 \text{ feet}$$

And let the other data be as follows :—

Live weight of horse	1425 lbs.
Weight of harness carried . . .	25 „
Weight of cart and contents . .	2500 „

The work consists of two parts, viz. raising the total mass through the vertical distance of 528 feet, and moving it through the horizontal distance 5253·5 feet. The latter cannot be calculated from the data given, as the effort depends upon the particular cart and road surface; but for present purposes it may be taken as one-fifteenth of the weight of the cart and contents, and one-twentieth of the weight of the horse and load (harness).

(*a*) To raise the mass against gravity

$$(1425 + 25 + 2500) \times 528 = 2{,}085{,}600$$

(*b*) To haul cart on level

$$\frac{2500}{15} \times 5253{\cdot}5 = \quad 875{,}583{\cdot}3$$

(*c*) Movement of horse and harness

$$\frac{1425 + 25}{20} \times 5253 = \quad \underline{380{,}878{\cdot}7}$$

$$\text{Total work done (ft.-lbs.)} \quad 3{,}342{,}062{\cdot}0$$

If the time occupied be known, the rate may be expressed as foot-pounds per second, or in any other way, but it does not affect the total amount of work done.

If exact information were required it would be necessary to determine the effort, *i.e.* the draught, and if that datum were known the result would be found directly by multiplying it by the distance.

The work done by horses when ploughing could also be calculated if all the data were known, but the draught cannot be deduced by any arithmetical process; it must be directly determined in each case, and it varies according to the nature of the soil and the slope of the land. In ploughing medium loamy soil with a pair of horses on the level, it is estimated that each animal performs, roughly, from 10 to 12 million foot-pounds of work in the day of eight hours.

For ordinary practical purposes, the capacity of horses for continuous work[1] may be put at 1 million foot-pounds per hour per 1000 lbs. live weight. Higher estimates have been given, but they are generally repudiated by men of practical experience. The engineers' unit of 550 foot-pounds per second is equal to nearly 2 million foot-pounds per hour. It should be remembered in this connection that when the amount of work is excessive, *i.e.* when the animal becomes fatigued, the output of work for a given amount of energy in the food is markedly diminished. On the other hand, light horses (600 or 700 lbs. live weight) give out more work for a given amount of energy in the food than heavy horses, *i.e.* those of about double the weight mentioned.

The terms "light," "ordinary," and "heavy work," commonly used in practice, are extremely vague, and quite incapable of scientific definition; but so far as can be ascertained they may generally be interpreted as follows:—

For Horses of 1000 lbs. Live Weight.

Light work means from $\frac{1}{2}$ to 1 million foot-pounds per hour
Ordinary ,, ,, 1 ,, $1\frac{1}{2}$,, ,, ,,
Heavy ,, ,, $1\frac{1}{2}$,, 2 ,, ,, ,,

---

[1] By continuous work is meant the average daily work for a considerable period. A good horse, when called upon for a spurt, can work at a much higher rate for short periods. This is probably the explanation of the very different estimates of the capacity of horses.

Whatever the amount of work may be, the amount of food should be at least roughly proportional. The actual amount of energy required for any given output of work is easily calculated by the method described above, and a quantity of suitable food sufficient to yield that amount of energy must be added to the previously determined maintenance ration or the animal will lose weight.

Internal Work.—Work such as trotting, hauling, etc., which alone has so far been considered, is commonly referred to as external work, to distinguish it from the work of circulation, respiration, digestion, etc., which is done within the animal's body. The distinction is of considerable importance in its bearing upon the practical question of feeding the animals.

The amount of work done in the internal economy of the animal has been the subject of numerous investigations. That it is not inconsiderable may be gathered from the fact that the work of circulation alone, *i.e.* the work done by the heart in pumping the blood through the body, is estimated at some 15,000 foot-pounds per hour in the case of men, and about 65,000 foot-pounds per hour—equal to 3·4 kt. per day—in the case of oxen. The work of circulation and respiration is practically constant for any given animal when at rest, but it is increased when the animal does external work. In any case it is quite independent of the nature of the food, provided the same is sufficient for all the vital functions.

The work of mastication and digestion stands in a very different relation. It is not directly affected by the conditions so far as work or rest is concerned, but it depends upon the quantity and quality of the food consumed. An animal when doing hard work may consume twice as much food as it does when at rest; obviously, then, if the food is of the same kind, the work of digestion will be doubled. Some kinds of foods are much more easily digested than others. A great deal more energy is expended by animals in digesting hard fibrous materials such as hay and straw than is required in the case of cakes, grains, and other more readily digestible substances. This energy is, of course, derived from the food. This is clearly brought out in the experiments described by Kellner. It was found that when a quantity of linseed cake, equivalent to 100 kt. of available energy, was added to a previously determined maintenance ration, F pounds of fat were stored up in the animal's body. The quantity of decorticated cotton cake equivalent to 100 kt. of available energy produced a like result—an increase of F pounds—when added to the maintenance ration. It was shown that this increase is the maximum obtainable; the corresponding amounts of nutrients in the form of pure digestible protein, fat, and carbohydrates produced no more.

The same is true of various other cakes and meals, but it is not true of hay and straw. The quantity of hay equivalent to 100 kt. of available energy produced only 0·6 F, or 0·7 F pounds of fat, *i.e.* from 30 to 40 per cent. less than might have been expected. The quantity of straw equivalent to 100 kt. of available energy produced only 0·2 F, or 0·3 F pounds of fat, *i.e.* from 70 to 80 per cent. less than might have been expected.

The energy which has disappeared—30 to 40 per cent. in the case of hay, and 70 to 80 per cent. in the case of straw—is accounted for by the work done in digesting these fodders. This conclusion is confirmed by the fact that when the straw was supplied in the finely ground condition so as to reduce the work of mastication and digestion, only about 35 or 40 per cent. disappeared; and when it was reduced to pulp by processes similar to those used in papermaking, only about 20 per cent. disappeared, *i.e.* were expended in the work of digestion.

The results mentioned above were obtained in experiments with ruminants. Pigs and horses have inferior digestive powers (p. 107), and are unable to utilise so much of the energy of coarse fibrous fodders as the ruminants. In fact, it has been shown that these animals may expend more energy in the work of digesting very coarse fodders than they get out of them. A horse fed entirely upon straw died of exhaustion (practically starvation) after about two months, although it was allowed an unlimited quantity of that fodder.

Dynamic Value of Food.—The energy which is expended on internal work cannot be used over again to perform external work. The static value, *i.e.* the amount of available energy equivalent to unit mass of the food, therefore, affords no true indication of the amount of external work that can be derived from such food. It is only the balance or surplus energy which remains after deducting what is consumed in the work of digestion that can be used for the latter purpose. This balance is called dynamic energy. The dynamic value of a food is the number of kt. of dynamic energy that can be obtained from unit mass (1 lb.) of the food. It is, in short, the static value minus what is consumed in the work of digestion.

The dynamic value of linseed cake and all the more readily digestible concentrated foods is practically the same as the static value, because little or none is used in the work of digestion. The dynamic value of hay is from 30 to 40 per cent. less than the static value of that substance; that of straw is from 70 to 80 per cent. less.

In the earlier parts of this chapter it was pointed out that a certain amount of food is required for maintenance of the animal, and that an additional quantity must be given sufficient to provide the amount of available energy equivalent to the work done. It will now be clear that this was intended to signify energy available for work, *i.e.* dynamic energy.

It has been said that all the energy expended in doing work of any kind whatever is ultimately transformed into heat. When the transformation takes place outside the animal's body—as it does when the work is external—the heat produced is entirely lost to the animal. But the energy expended in the performance of internal work is transformed into heat within the body, and therefore helps to maintain its temperature.

The heat which is given off by radiation (p. 126) consists, in part, of the energy which has been used for the work of circulation, respiration, and other vital functions which never cease during life. In short, the energy required for these functions is included in the maintenance rations.

Application of the Principles.—The energy expended in the work of digestion differs only in respect of the fact that when the animal does external work it consumes more food, and the work of digestion is correspondingly increased. But as the heat derived from this additional internal work also helps to maintain the temperature of the body, an equivalent amount may be deducted from the maintenance ration.

For example, suppose it has been found that a certain horse requires a food equivalent to 35 kt. per day for maintenance, and that the static value of the hay is 1·83 kt. per lb., then [35 ÷ 1·83 =] 19·1 lbs. is the quantity of hay required. Further, if the animal, on being put to work, does 9·6 million foot-pounds per day, since 463,200 foot-pounds can be obtained from 1 kt. of dynamic energy, [9·6 ÷ 0·4632 =] 20·7 kt. is required for the whole. If the additional food required for the work be given in the form of oats, the dynamic value of which is 2·5 kt. per lb., then [20·7 ÷ 2·5 =] 8·3 lbs. is the quantity required. But the thermic value of the oats is 2·61 kt. per lb., and 8·3 lbs. would, therefore, furnish [2·61 × 8·3 =] 21·7 kt. The difference between these two numbers [21·7 — 20·7 =] 1 kt. represents the energy expended on the work of digesting the oats; and, as this energy appears as heat in the body of the animal and helps to maintain its temperature, a quantity of hay (0·54 lb.) equivalent to 1 kt. (thermic) may be withdrawn.

It will be seen, therefore, that the ration for simple maintenance is 19·1 lbs. of hay, but the ration for work is 18·56 lbs. of hay and 8·3 lbs. of oats. The amount of hay (0·54 lb.) which can be withdrawn is so small that it can be ignored. And this is usually the case, because the concentrated foods given for working rations are usually very easily digestible, and very little energy is expended on the process.

If a large amount of fodder of a coarser character were added to the original maintenance ration the case would be different. Suppose, for example, that it were possible to derive the stipulated amount of work from hay, the quantity required would be 9·6 ÷ (0·4632 × 1·1) = 18·8 lbs. But this amount is not to be added to the original maintenance ration;

for 40 per cent. of it [18·8 × 0·40] = 7·52 lbs. is consumed in the work of digestion; this energy appears as heat, and helps to maintain the temperature of the animal's body; 7·52 lbs. may, therefore, be deducted from the original maintenance ration, and the 18·8 lbs. required for work is to be added to the difference. The total amount of hay required, therefore, is 19·1 − 7·52 + 18·8 = 30·38 lbs.

The last example is intended merely to illustrate the method of investigation. A horse of 1000 lbs. live weight would probably experience no difficulty in consuming and digesting 30 lbs. of hay per day, but it does not follow that such a ration would enable it to do the specified amount of work in the given time. Not only is hay difficult to digest, but the process is a slow one, and the animal cannot therefore put forth the effort rapidly. It is a matter of practical experience that horses are sluggish and cannot work fast when fed entirely upon hay. When they are required to work rapidly, the additional food (for work) should be of a readily digestible character. It is found that, for some reason, oats are the best, but this food may be wholly or partially replaced by mixtures of maize, beans, etc., without obvious disadvantage. A ration consisting entirely of hay would be more suitable for oxen than for horses, because these animals are better able to digest such materials, and also because, in any case, they work at a slower rate. Even oxen, however, work much better when fed on rations consisting partly of corn. The difference is, perhaps, more correctly stated by saying that in the case of oxen a larger proportion of the ration may consist of hay.

It will be noticed that the sluggishness of horses when fed entirely upon hay is attributed to the fact that this food takes a long time to digest, and not to a deficiency of nutrients in it. Matters are not, therefore, improved in this respect by giving larger quantities of the coarse fodder instead of the more readily digestible corn.

A similar phenomenon is noticed in regard to fattening animals. They may improve up to a certain point, but never grow really fat on rations of coarse fodder, however much they receive. For the same reason grazing animals do not fatten readily, except on the very finest pastures, even if they have an unlimited area at their disposal, unless they are also given a certain amount of readily digestible cakes and meals.

Pecuniary Considerations.—These considerations are also of importance from a pecuniary point of view. The cost of the various foods per 1000 kt. of dynamic energy is shown in the last column of the tables (p. 166). It will be seen that in this case also roots come out near the top, but owing to their bulky and watery character they cannot be largely used as rations for working horses. Of the dry foods, rape cake is distinctly the cheapest at the prices assumed. It is closely followed by rice-meal, maize, bran, pollards, and locust beans. All of these yield dynamic energy at a cost of about £1 per 1000 kt., but with the exception of rape cake they are all rather deficient in nitrogen. Decorticated cotton cake, soya-bean cake, and linseed cake cost about 23*s*. to 25*s*., and barley, wheat, and oats from 25*s*. to 30*s*. per 1000 kt. Of the cereals, rye, at 22*s*., is the cheapest, and oats, at 30*s*. per 1000 kt., the dearest. Undecorticated cotton cakes, hay and straws are all more expensive as a source of dynamic energy.

The position of the coarse fodders—hay and straw—is of peculiar interest from this point of view. It was shown (p. 142) that they are amongst the cheapest foods for maintenance, because the whole of the energy of the digestible matter is available for that purpose; but because so much is spent in the work of digestion they are amongst the most expensive substances as a source of dynamic energy. Straws, it will be noticed, are markedly inferior to hay in this respect. The quality of the hay, too, makes a much greater difference to the cost of the dynamic energy than to that of the thermic. The price of the best quality of meadow hay works out to about 22*s*. and that of the inferior to 30*s*. per 1000 kt. of dynamic energy—truly a case where the best is the cheapest; whereas at the prices quoted the inferior quality is rather cheaper than the best as a source of thermic energy.

The general conclusion to be drawn from these data is that the energy required for the performance of work — apart from the simple maintenance of the animal—can be most cheaply as well as most effectively obtained from the more highly concentrated and readily digestible foods, notwithstanding the much higher price per ton of the latter. This is not, perhaps, entirely consistent with the practice of farmers and horse-keepers, but it accords well with the experience of those who have been most successful.

Conclusions.—The rations for working horses, then, comprise two parts—one for the simple maintenance of the animal, the other to provide the energy for the performance of work. For reasons of pecuniary economy the former should consist mainly of hay or similar coarse fodder, and the amount of it should be determined by the size of the animal, as described in Chapter IX. It should provide about $\frac{3}{4}$ lb. of digestible protein to each 35 kt. of static or thermic energy. The latter—the portion which provides the energy for work—should consist of readily digestible foods. The amount is independent of the size of the animal and should be determined by the amount of work done. It is to be calculated from the dynamic value of the food, and should contain at least 1 lb. of digestible protein to every 30 or 40 kt. of dynamic energy in the food.

Feeding Standard for Working Horses.—The statement above does not imply that the constituents of one food are used exclusively for maintenance, and those of another for work. It is not improbable that such differentiation may occur to a certain extent owing to the difference in the digestibility of the two kinds of food, but it is by no means exclusive. Probably, in a theoretically exact ration, all the more readily digestible constituents of both portions would be used for work, and the less readily digestible for maintenance. For this reason, then, and also because any deficiency in either part of the ration can be, at least partially, made up from excess in the other, it is customary to add together the digestible nutrients of the maintenance portion and those of the portion for work. The sum is called a "feeding standard" for working horses.

For example, if we take the maintenance rations of horses to be the same as those of oxen of similar size, *i.e.* 35 kt. for an animal of 1000 lbs. live weight, the corresponding amounts of nutrients would be as before (p. 135), $\frac{3}{4}$ lb. digestible protein, and 8·3 lbs. of non-nitrogenous nutrients reckoned as starch. And if we further assume that the animal does 14 million foot-pounds of work per day, the dynamic energy required would be 30 kt. = 8·0 lbs. of starch. But with such a large addition of non-nitrogenous matter it is necessary also to increase the protein. The amount of non-nitrogenous matter may be correspondingly reduced and the total feeding standard for horses doing hard work would therefore be as follows:—

	Digestible nutrients.	
	Protein. lbs.	"Starch." lbs.
For maintenance	0·75	8·3
,, work	1·00	6·7
Feeding standard[1] . . .	1·75	15·0

This method of stating the requirements of working horses is open to very serious objection. The nutrients of the maintenance ration correspond to the total available thermic energy of the food, and those of the special food for work correspond to the dynamic energy. Confusion must result if these two are added together. When both are expressed in terms of equivalent amounts of starch or other nutrient, the difficulty is only disguised, not overcome. Attempts have been made to solve the problem by counting only the dynamic energy of both portions of the food which may then be reckoned as starch. This method, however, is a highly artificial one. It must either involve the assumption that the maintenance portion of the ration is of a certain constant degree of digestibility; or it must be accompanied by a statement of the amount of total organic matter. In any case, the feeding standard, when expressed in terms of total dynamic energy or

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[1] Kellner's estimate is 2·2 lbs. of protein and 15·7 lbs. of non-nitrogenous nutrients (reckoned as starch); that of Wolff is 2·3 lbs. of protein and 14·5 lbs. of non-nitrogenous nutrients (reckoned as starch). The differences are probably to be attributed to the difference in the estimates of the amount of work done.

the corresponding amount of starch, must be correspondingly reduced. This makes it appear as if the requirements of the animal were less than they actually are. The question is further discussed under the head of starch values (p. 218).

The simplest way out of the difficulty is not to add the nutrients of the two portions of the food together. It is not necessary or advantageous to do so. They represent essentially different things which, in practice, are usually kept distinct. Farmers are accustomed to think in terms of hay and corn—not of a mixture of the two—and in a more or less approximate fashion they try to adjust the quantity of the former according to the size of the animal, and that of the latter according to the amount of work done. It is a simple matter to determine suitable rations for maintenance. It is equally simple to determine suitable rations for work, if the necessary data be known. If these two things are provided for, that is all that is required; and all trouble and confusion are avoided by keeping them distinct.

Rations.—For practical purposes, the author considers the following a good working rule by which to calculate rations for horses:—

(*a*) An amount of hay corresponding to the *thermic* energy required for maintenance. This can be calculated by means of the formula.

(*b*) For hard work, an amount of oats or mixed corn corresponding to an equal number of kilo-pound-units of *dynamic* energy. For ordinary or light work the corn should be reduced by from 25 to 50 per cent. of the above amount according to the interpretation put upon these terms.

(*c*) The allowance of digestible protein should be not less than 1 lb. for each 50 kt. of thermic energy in the maintenance ration and 1 lb. for every 30 or 40 kt. of dynamic energy in the special food for work.

Example.—A horse of 1000 lbs. live weight requires 35 kt. of thermic energy, and when put to heavy work should receive additional food equivalent to an equal amount (35 kt.) of dynamic energy. This could be obtained from 19 lbs. of meadow hay and 14 lbs. of oats. The total ration would contain 2 lbs. of digestible protein and 16·25 lbs. of non-nitrogenous nutrients reckoned as starch.

The following rations are quoted[1] as having been used in practice for "large farm horses at work in winter." Ration II. is described as the "approximate average of six farmers in different parts of England." The amounts of protein and of thermic and dynamic energy in each are calculated from the figures given in the tables.

RATION I.

Feeding stuffs.	Digestible protein.	Thermic energy.[2]	Dynamic energy.
	Lb.	Kt.	Kt.
18 lbs. Meadow hay	0·72	32·9	—
2 ,, Oat straw	0·02	3·1	—
18 ,, Oats	1·62	2·4	44·6
2 ,, Beans	0·38	0·2	5·5
Total . .	2·74	38·6	50·1

RATION II.

15 lbs. Meadow hay	0·60	27·4	—
16 ,, Swedes	0·04	5·1	—
10½ ,, Oats.	0·95	1·4	26·1
4½ ,, Beans	0·86	0·4	12·5
Total . .	2·45	34·3	38·6

RATION III.

10 lbs. Meadow hay	0·40	18·3	—
5 ,, Oat straw	0·05	7·8	—
15 ,, Oats	1·35	2·0	37·2
2 ,, Beans	0·38	0·2	5·5
Total . .	2·18	28·3	42·7

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[1] McConnel's "Agricultural Notebook."

[2] The dynamic energy of the coarse fodders is included with the thermic, but in the finer foods the two are stated separately.

In the absence of exact information regarding the size of the horses or the amount of work done by them, it is difficult to compare these rations or to criticise them. Two things, however, are evident, viz. (1) the proportion of protein to energy accords fairly well with the conclusions arrived at (p. 160); (2) if the conditions are at all comparable, then either Ration I. is excessive or the other two are inadequate.

Maintenance rations for horses of different sizes may be calculated by means of the formula (p. 128) as follows :—

Live weight of animal	1000	1500	2000 lbs.
Thermic energy required	35	46·5	56·8 kt.

The thermic energy of the coarse fodder in Ration I. is suitable for horses of 1100 to 1200 lbs., in Ration II. for horses of 900 to 1000 lbs., and in Ration III. for horses of 700 to 800 lbs. live weight. These would hardly be described as "large farm horses." The inference is that the coarse fodder is not by itself sufficient for maintenance, and some of the energy of the finer and more expensive foods must, therefore, be devoted to this purpose. In that respect the rations are not of the most economical character.

Large horses would presumably be required to do heavy work, for which large amounts of dynamic energy are required.

Work (million foot-pounds) . .	12	14	16
Dynamic energy required (kt.) .	27·5	32·1	36·6

The dynamic energy of Rations II. and III. is more than sufficient for the hardest work, but it is probable that horses of less than 1000 lbs. live weight could not do so much work in a day. If they did only 14 million foot-pounds of work, there would be a certain balance of energy which when added to the maintenance ration would make that suitable for horses of 1200 lbs. live weight. Ration I. provides enough thermic energy for horses of this size, and much more dynamic energy than is required for the hardest work. This ration must, therefore, be deemed excessive unless the horses were very much larger than the others, and in that case it is uneconomical.

The two following rations, taken from the same source, may be investigated in a similar manner:—

APPROXIMATE AVERAGE OF TEN TRAMWAY COMPANIES.

Feeding stuffs.	Digestible protein.	Thermic energy.	Dynamic energy.
	Lb.	Kt.	Kt.
11 lbs. Meadow hay	0·44	20·1	—
1 ,, Oat straw	0·01	1·6	—
½ ,, Bran	0·05	1·2	—
10 ,, Maize	0·70	—	33·1
2½ ,, Beans	0·47	0·2	6·9
5 ,, Oats	0·45	0·6	12·4
Total . .	2·12	23·7	52·4

This ration contains a sufficient amount of protein, but the proportion of fine to coarse fodders is too large for the highest economy. If the hay were increased to about 20 lbs. and the maize reduced to 5 lbs., the ration would still be satisfactory from a theoretical standpoint, and the cost would be considerably reduced.

ARMY RATIONS FOR CAVALRY HORSES IN CAMP.

Feeding stuffs.	Digestible protein.	Thermic energy.	Dynamic energy.
	Lb.	Kt.	Kt.
12 lbs. Meadow hay	0·48	22·0	—
8 ,, Oat straw . . .	0·08	12·6	—
12 ,, Oats	1·08	1·6	29·8
Total . .	1·64	36·2	29·8

The thermic energy of the coarse fodder corresponds to the maintenance requirements of horses of about 1000 to 1100 lbs. live weight; and the dynamic energy is sufficient for 13·8 million foot-pounds, which may be regarded as a very fair day's work for horses of that size. From the point of view of the conclusions set forth in this chapter, this ration appears to be almost perfectly balanced both as regards efficiency and pecuniary economy.

Feeding stuffs.	T.F.V.	Static or Thermic value.		Dynamic value.		Quantity required to produce 1000 kt.		Digestible protein per 1000 kt.		Assumed price.	Cost per 1000 kt.	
	Per lb.	Per lb.	% of T.F.V.	Per lb.	% of static.	Static.	Dynamic.	Static.	Dynamic.		Static.	Dynamic.
	Kt.	Kt.	Kt.	Kt.	Kt.	Lbs.	Lbs.	Lbs.	Lbs.		s. d.	s d.
Pure digestible nutrients—												
Fat of oil cakes	9·4	9·4	100·0	9·4	100	105	105	—	—			
,, cereals and pulse	9·0	9·0	100·0	9·0	100	111	111	—	—			
,, hay and straw	8·5	8·5	100·0	8·5	100	118	118	—	—			
Protein	5·8	4·93	85·0	4·93	100	203	203	203	203			
Starch and cellulose	4·18	3·76	89·9	3·76	100	266	266	—	—			
Sugars	3·9	3·51	90·0	3·51	100	286	286	—	—			
Oil-cakes—												
Cotton cake, decorticated	4·66	3·23	69·1	3·14	97	309	318	105·0	108·1	£8 0*s.* per ton	22 1	22 8
,, undecort. Egyptian	4·07	2·01	49·5	1·69	84	500	592	77·5	91·8	£6 0*s.* ,,	26 9	31 8
,, undecort. Bombay	3·98	1·86	46·7	1·56	84	538	641	75·3	89·7	£5 10*s.* ,,	26 5	31 0
Linseed cake	4·49	3·34	74·4	3·24	97	299	308	74·7	77·0	£9 0*s.* ,,	24 0	24 8
Rape cake	4·49	2·75	61·2	2·61	95	363	383	80·0	84·3	£5 10*s.* ,,	17 9	18 9
Sesame cake	4·59	3·52	70·7	3·15	97	307	317	104·4	107·8	£7 12*s.* ,,	19 3	21 5
Earthnut cake	4·79	3·63	75·6	3·55	98	275	282	110·0	112·8	£8 12*s.* ,,	21 2	21 7
Palmnut cake	4·37	2·96	67·4	2·96	100	337	337	47·5	47·5	£6 5*s.* ,,	18 6	18 6
Cocoanut cake	4·37	3·21	73·4	3·21	100	310	310	52·7	52·7	£7 10*s.* ,,	20 10	20 10
Soybean cake	4·50	3·08	68·4	3·02	98	324	331	110·2	112·5	£8 0*s.* ,,	23 2	23 7
Soybeans	5·00	3·63	72·6	3·56	98	275	281	78·3	80·1			
Linseed	5·97	4·86	81·5	4·81	99	206	208	35·0	35·4	£3 5*s.* per 416 lbs.	32 2	32 6

Pulse grains—												
Peas	3·99	2·92	73·2	2·86	98	342	350	58·1	59·5	£2 16*s.* per 504 lbs.	38 0	38 10
Beans	3·90	2·85	73·2	2·77	97	351	361	66·7	68·6	£2 6*s.* ,, 532 ,,	30 4	31 2
Cereal grains—												
Wheat	3·86	3·00	77·6	2·85	95	333	351	30·0	31·6	£2 0*s.* ,, 504 ,,	26 5	27 10
Barley	3·78	3·01	79·5	2·97	99	332	336	29·9	30·2	£1 15*s.* ,, 448 ,,	26 0	26 3
Oats	3·97	2·61	65·7	2·48	95	383	403	34·5	36·3	£1 5*s.* ,, 336 ,,	28 2	30 0
Rye	3·87	2·98	76·9	2·84	95	334	352	30·1	31·7	£1 10*s.* ,, 480 ,,	20 10	22 0
Maize	4·08	3·31	80·9	3·31	100	302	302	21·1	21·1	£7 15*s.* per ton	20 11	20 11
By-products, etc.—												
Pollards (middlings)	4·00	2·97	74·2	2·97	100	336	336	40·3	40·3	£7 0*s.* ,,	21 0	21 0
Sharps	4·00	2·74	68·4	2·16	79	365	463	40·1	50·9	£6 3*s.* ,,	20 0	25 5
Bran	3·90	2·46	62·9	1·89	77	406	529	40·6	52·9	£5 0*s.* ,,	18 1	20 8
Rice meal	4·21	2·77	65·9	2·77	100	361	361	21·7	21·7	£6 0*s.* ,,	19 3	19 3
Malt	4·00	2·85	71·1	2·74	96	351	365	21·1	21·9	£1 15*s.* per 336 lbs.	36 6	38 0
Malt dust (coombs)	3·92	2·17	55·3	1·63	75	460	613	52·9	70·5	£5 10*s.* per ton	22 7	30 1
Brewer's grains (wet)	1·19	0·71	59·4	0·61	86	1408	1639	56·3	65·6	£0 18*s.* ,,	11 4	13 2
,, ,, (dry)	4·23	2·47	58·4	2·07	84	404	483	56·6	67·6	£5 10*s.* ,,	19 10	23 9
Gluten meal	4·54	3·42	75·4	3·28	96	292	305	96·4	100·6	£8 3*s.* ,,	21 3	22 2
Gluten feed	4·26	3·22	75·5	3·06	95	310	326	65·1	68·5	£6 5*s.* ,,	17 3	18 2
Locust beans	3·67	2·90	78·8	2·81	97	344	356	12·0	12·5	£6 10*s.* ,,	19 11	20 8
Molasses (treacle)	2·92	2·04	70·0	2·04	100	490	490	—	—	£4 18*s.* ,,	21 7	21 7
Coarse fodders—												
Meadow hay (good)	3·58	1·92	53·7	1·42	74	521	704	26·1	35·2	£3 10*s.* ,,	16 3	22 0
,, (medium)	3·56	1·83	50·1	1·10	60	546	910	21·8	36·4	£3 5*s.* ,,	15 11	26 4
,, (inferior)	3·59	1·48	41·3	0·77	49	675	1370	16·9	34·2	£2 10*s.* ,,	15 1	30 7
Clover hay (average)	3·57	1·83	51·2	1·28	70	546	781	30·0	42·9	£4 0*s.* ,,	19 6	27 10
Straw, pea	3·55	1·44	40·6	0·63	44	694	1587	24·3	55·5	£2 10*s.* ,,	15 5	36 11
,, bean	3·63	1·54	45·7	0·74	48	643	1351	20·9	43·0	£2 10*s.* ,,	14 9	30 2
,, wheat	3·51	1·33	37·9	0·37	28	751	2703	1·9	6·8	£2 10*s.* ,,	16 9	60 4
,, barley	3·52	1·57	44·6	0·72	46	636	1390	3·2	7·0	£2 10*s.* ,,	14 2	31 0
,, oat	3·52	1·56	44·0	0·67	43	641	1492	6·4	14·9	£3 0*s.* ,,	17 2	40 0
,, rye	3·51	1·38	39·3	0·40	30	724	2500	3·6	12·5	£2 10*s.* ,,	16 2	56 0

APPENDIX TABLES—*continued.*

Feeding stuffs.	T.F.V.	Static or Thermic value.		Dynamic value.		Quantity required to produce 1000 kt.		Digestible protein per 1000 kt.		Assumed price.	Cost per 1000 kt.	
	Per lb.	Per lb.	% of T.F.V.	Per lb.	% of static.	Static.	Dynamic.	Static.	Dynamic.		Static.	Dynamic.
	Kt.	Kt.	Kt.	Kt.	Kt.	Lbs.	Lbs.	Lbs.	Lbs.		*s.* *d.*	*s.* *d.*
Green fodders—												
Pasture grass	0·87	0·52	59·8	0·47	91	1923	2128	28·8	31·8			
Clover (green)	0·81	0·48	58·9	0·41	86	2083	2439	41·7	48·8			
Vetches ,, ...	0·71	0·38	54·1	0·32	83	2632	3125	52·6	62·5			
Lucerne ,, ...	1·00	0·48	48·1	0·38	79	2083	2632	41·7	52·6			
Cabbage ,, . .	0·59	0·38	64·3	0·36	94	2632	2777	39·5	41·7			
Rape ,, ...	0·60	0·34	57·0	0·30	87	2941	3333	44·1	50·0			
Roots—												
Turnips	0·36	0·24	67·0	0·19	77	4166	5263	10·4	13·2	£0 8*s.* per ton	14 10	18 9
Swedes	0·46	0·32	68·2	0·25	80	3125	4000	7·8	10·0	£0 10*s.* ,,	13 11	17 10
Mangels	0·48	0·34	70·9	0·25	72	2941	4000	7·6	10·0	£0 12*s.* ,,	15 9	21 5
Carrots.	0·52	0·40	77·1	0·35	87	2500	2857	2·5	2·9			
Sugar beet.	0·95	0·76	80·0	0·57	75	1316	1754	6·6	8·8	£1 0*s.* ,,	11 9	15 11
Potatoes . . .	1·06	0·72	67·9	0·72	100	1389	1389	1·4	1·4	£1 10*s.* ,,	18 6	18 6
Milk, etc.—												
Whole milk (cow's) . .	0·75	0·69	92·8	0·69	100	1449	1449	47·1	47·1			
Skim ,, ,, . .	0·46	0·40	86·5	0·40	100	2500	2500	91·3	91·3			
Separated,, ,, .	0·42	0·37	86·9	0·37	100	2702	2702	94·6	94·6			
Whey ,, . .	0·28	0·21	71·8	0·21	100	4762	4762	—	—			

CHAPTER XI

MILK PRODUCTION

The production of milk by cows is influenced, both as to quality and quantity, by many different circumstances. These fall, for the most part, to be considered under the chemistry of dairying. The present chapter deals with the question only so far as the food of the animal is concerned.

It is clear at the outset that the cow cannot produce milk out of nothing. All that it can do is to transform the constituents of the food into the constituents of milk. It has been shown in previous chapters that each animal requires a certain minimum ration for maintenance. This food undergoes oxidisation. The products are given off from the animal's body in the form of carbon dioxide, water, urea, etc., and the resulting energy (heat) is dissipated in various ways. If any part of this food is not oxidised, but turned into milk, or used in any other way, the remainder will be inadequate for the sustenance of the animal, which will, therefore, lose weight. If milk is to be produced, and the weight of the animal maintained, the constituents of the milk must be derived from other sources, *i.e.* from additional food supplied for the purpose. The nature and quantity of this additional food must correspond in some degree to the composition and quantity of the milk produced. A primary indication of the requirements may, therefore, be obtained from a study of the milk itself.

Milk.—The composition of cow's milk is subject to considerable variation from causes which need not now be discussed. For present purposes the average may be taken to be as follows:—

	Per cent.
Water	87·5
Nitrogenous matter	3·5
Fat	3·8
Milk sugar	4·5
Ash	0·7
	100·0

Apart from water and ash, which may be ignored for the present, 100 lbs. (10 gallons) of cow's milk contains, on the average, 3·5 lbs. of protein, 3·8 lbs. of fat, and 4·5 lbs. of milk sugar, all of which are derived, directly or indirectly, from the food.

The quantity, *i.e.* the daily yield per head, varies within wide limits. Cows never produce 100 lbs. of milk per day.[1] Prize-winners at shows rarely give more than about half that amount, and the average for ordinary good milkers is probably not much over a quarter—about 2½ to 3 gallons per day. The yield is always greatest soon after calving, and declines steadily till the end of the period of lactation.

That portion of the food which is given in addition to the maintenance ration to provide for milk production must be of a readily digestible character. The constituents of any portion of the food that is spent on the work of digestion are lost to the milk; and if the process of digestion occupies a long time, the formation of milk must be slow and the yield consequently small.

Protein.—The protein of the milk must necessarily be derived mainly from the protein of the food. It cannot be formed from the non-nitrogenous nutrients (fat and carbohydrates); but various experiments tend to show that a certain amount of

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[1] The records of the University of Wisconsin (Bul. 106) contain an account of a cow, "Johanna," which gave over 100 lbs. of milk per day for several days in succession. In numerous instances cows have given between 80 and 90 lbs. of milk per day. These cases are, however, exceptional.

protein may be formed from the non-protein nitrogenous compounds (amides) and the non-nitrogenous nutrients together. This, however, could occur only when there is a deficiency of protein and a considerable excess of non-nitrogenous nutrients, together with the necessary amides, in the food. Under ordinary circumstances, we may take it that the nitrogenous matter of the milk is derived entirely from the true protein of the food. The question remains what quantity of this nutrient is required.

It was shown (p. 133) that for animals of 1000 lbs. live weight the maintenance ration must supply a minimum of about ½ lb. of digestible protein per day, and that on other grounds it is generally desirable to allow more. In the case of cows in milk it has been found that when the rations contain a sufficient amount of digestible non-nitrogenous nutrients, the whole of the *excess* of protein, beyond what is actually required for maintenance, can be used for milk production. For example, if the maintenance ration contain 1 lb. of digestible protein, and a certain quantity of digestible fat and carbohydrates is added to it, the extra ½ lb. of protein will not be oxidised, but will appear in the milk. If each pound of milk contains 0·035 lb. (3·5 per cent.) of protein, the extra ½ lb. would be sufficient for about 14 lbs. of milk. Theoretically, then, the rations for milk cows should contain at least 0·035 lb. of digestible protein, in addition to the quantity (½ lb.) required for maintenance, for each pound of milk produced.

Fat.—Any excess of protein, beyond what is required for maintenance and what appears as such in the milk, undergoes chemical change. The nitrogenous part is split off and discharged in the urine, but the remainder—or some of it—is converted into milk fat (p. 113). It will presently be shown that milk fat can be produced at less cost from other constituents of the food, but a certain excess of protein is nevertheless desirable; it appears to stimulate the mammary glands and increase the secretion of milk. Perhaps it would be more correct to say that unless a certain excess of protein (beyond what is required for maintenance, and what appears as such in the milk) is given in the food, the yield of milk rapidly declines.

Milk fat may also be formed from the fat of the food; but, on comparison, it will be found that, in general, the milk contains more fat than could have been formed from the fat and excess of protein in the food taken together. No doubt is entertained that milk fat may be, and commonly is, formed also from the carbohydrates.

Now, though milk fat may be formed from all or any of the digestible nutrients of the food, these are not all of equal value for this purpose (fat formation). The dynamic values of milk fat, protein, and starch are 9·4 kt., 4·93 kt., and 3·76 kt. respectively; and experiments show that fat and starch have much the same relative value (2·5 to 1) for the formation of fat in the animal's body. The relative value of protein as a fat former is not proportional to its dynamic value; it is probably no greater, or perhaps actually a little less, than that of starch (p. 197); and, as it costs much more, the production of fat from protein cannot be regarded as an economical process (in the pecuniary sense), though it may be to a certain extent a necessary one. At any rate, it is important to remember that it is only *excess* of protein that is available for fat formation.

Milk Sugar.—Under ordinary circumstances there can be little doubt that the milk sugar is formed mainly from the digestible carbohydrates of the food. A certain amount may be formed from protein when the latter is present in excess. Milk sugar is probably not, as a rule, formed from the fat of the food. On the contrary, fat is formed from the carbohydrates (p. 113), and it is probable that the fat formed from protein passes through the stage of carbohydrate.

Since the fat and carbohydrates of the food perform similar functions, and have a relative value of 2·5 to 1, they may be conveniently considered together on this basis. Thus, we find that [$0·038 \times 2·5 + 0·045 =$] 0·14 lb. of total digestible non-nitrogenous nutrients, reckoned as starch, is the minimum required to produce the fat and sugar in each pound of milk.

Total Nutrients.—It has been shown that each pound of cow's milk contains, on the average, 0·035 lb. of protein, and fat and sugar together equivalent to 0·14 lb. of pure starch. It is clear, therefore, that the milk cannot be produced without loss of body weight, unless the cow receives and absorbs into its system at least these amounts of nutrients in addition to what is required for simple maintenance. So far, however, we have no assurance that these quantities are sufficient. When the matter is put to the test, it is found that the quantities mentioned may serve when the yield is very small; but when it is greater, relatively larger quantities are required. As the amounts of protein and non-nitrogenous nutrients are to be increased correlatively, it is convenient for purposes of calculation to add them together. Thus we obtain [0·035 + 0·14 =] 0·175 lb. of total nutrients, of which one-fifth must be protein, as a fundamental figure.

If the amount of food required were directly proportional to the yield of milk, a cow producing 4 gallons (40 lbs.) per day would require [0·175 × 40 =] 7 lbs. of total digestible nutrients. Experience shows that if the supply of food be limited to this theoretical minimum, the yield of milk rapidly diminishes, and that in order to sustain it at that level,[1] not less than 10 lbs. of total digestible nutrients are required, in addition to the maintenance ration. On this basis, the amounts of digestible nutrients for any yield of milk may be calculated by means of the following formulæ:—

$$N = \left(\frac{180M}{1000} + \frac{2M^2}{1000}\right) \qquad P = \frac{N}{5}\,;\ C = \frac{4N}{5}$$

$$\therefore\ P = \frac{2(M^2 + 90M)}{5000} \qquad C = \frac{8(M^2 + 90M)}{5000}$$

N is the total amount (lbs.) of digestible nutrients; M is the yield (lbs.) of milk; P is the quantity (lbs.) of protein; and C is the quantity (lbs.) of non-nitrogenous nutrients reckoned as starch. In practice, it is desirable that a certain amount of the non-nitrogenous matter should be given in the

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[1] That is, to prevent a decline more rapid than that due to the advance in the stage of lactation.

form of fat; but the quantity of this ingredient should not, as a rule, exceed the equivalent of $\frac{1}{10}$ of the starch.

The quantities calculated by the formulæ are strictly those required for milk production, as apart from maintenance, increase, work, etc. If there be any question of such, a further addition should be made on account of it. For instance, nothing has been allowed for the work of digestion of that part of the food given for milk production. The point is not, perhaps, of much importance, because such foods should be, and usually are, of a highly concentrated and readily digestible character. Still, in many of them, about 5 per cent. is lost in this way, as shown in the tables (p. 166), and, on a strict calculation, allowance should be made for this. The maintenance ration, previously considered, includes the amount spent in digesting that portion of the food, but not the amount spent in digesting the concentrated food given for milk production.

Feeding Standards.—In order to make a feeding standard for milk cows, the nutrients of the maintenance ration are added to those of the food required specially for milk production. The former varies according to the size of the animals, and the latter according to the yield of milk. If $\frac{1}{2}$ lb. of digestible protein and 8·3 lbs. of non-nitrogenous nutrients, reckoned as starch, be taken as the standard for maintenance of cows of 1000 lbs. live weight (cf. p. 134), the feeding standards would be as follows:—

Yield.	Digestible protein.	Nutrients. "Starch."
	Lb.	Lb.
1 gallon per 1000 lbs. live weight .	0·9	9·9
2 ,, ,, ,, . .	1·4	11·8
3 ,, ,, ,, . .	1·9	14·1
4 ,, ,, ,, . .	2·7	16·5

The objections to such feeding standards for milk cows are similar to those offered in regard to the standards for working horses (p. 160), but they are even more weighty and perhaps more obvious. The two variable factors—the size of the animal and the yield of milk—are quite independent. The former determines the amount of coarse fodder, and the latter the amount of concentrated food. The digestible nutrients of the maintenance portion—whichever food it may be derived from—undergo oxidation, and the value of the food corresponds to the amount of thermic energy thereby produced. The nutrients of the special food for milk production undergo sundry changes, but they are not oxidised, and the value of the food depends upon the readiness and completeness with which they are converted into the constituents of the milk.

No advantage is to be gained by adding together the nutrients of the two kinds of food, and for purposes of calculation the author thinks it desirable to keep them distinct.

Influence of the Food.—It is extremely difficult to ascertain exactly what is the effect of any food upon the yield and composition of milk, because so many disturbing factors tend to obscure it. Two methods have been chiefly employed in experiments of this kind. They are known as the group system and the period system respectively.

In the group system a number of cows—say twenty—are divided into two groups of ten each; and they are so arranged that the total yield of milk and all other circumstances in each group are as nearly as possible alike. The cows in each group are generally given the same maintenance ration, but different food for milk production; and any differences in the yield or quality of the milk are attributed to this difference in feeding.

In the period system, all the cows are fed alike, and the time during which the experiment lasts is divided into three equal periods of, say, twenty-eight days each. The cows receive the same rations in the first and third periods, but a different one in the middle or intermediate period. Both yield and quality of the milk change continuously as the stage of lactation advances, but both the direction and magnitude of the change are approximately constant under constant conditions. Any disturbance of the constancy of the change observed during the middle period may, therefore, be attributed to the influence of the food given at that time.

This method, it is said, has given very satisfactory results in practice when applied to a considerable number of animals at once. The fundamental assumption, however, does not hold for individuals; or at least, the fluctuations due to other disturbing factors do not permit of accurate and reliable observations being made in this way in individual cases. The two methods should be regarded as complementary; each forms a useful check upon any inferences that may be drawn from the other.

It was formerly supposed that the yield and composition of the milk could be to a large extent controlled by the food. More recent experiments tend to show that such is not the case; and many people now believe that the food has very little or no influence at all.

A good deal, perhaps, depends upon the point of view from which the subject is regarded. The natural capacity of cows for the production of milk varies very widely; and no kind or quantity of food that can be given will convert a bad milker into a good one. On the other hand, a certain minimum ration is indispensable for the maintenance of the animal and production of the maximum yield possible under the conditions. If the rations be reduced below this minimum, whatever it may be, the yield of milk will be speedily diminished.

Some cows, it is true, exhibit such a strong inherited tendency to produce milk that they continue to yield large quantities—perhaps nearly the maximum—even when the rations are insufficient; but under these conditions the cow is bound to lose weight. It is obvious, therefore, that the process cannot be continued very long without reacting on the yield. This conclusion is entirely confirmed by the experience of practical dairymen who are accustomed to sum up the matter in the phrase, "Feed your cow, and she will feed you." Excessive amounts of food should, however, be avoided; not only on pecuniary grounds, but also because it has been found that, when the rations are largely disproportionate to the yield of milk, the animal grows fat, the glands become sluggish, and the yield is diminished.

Probably no one now denies that the yield of milk may be diminished by insufficient feeding. That it may be actually increased by more suitable rations is clearly demonstrated by

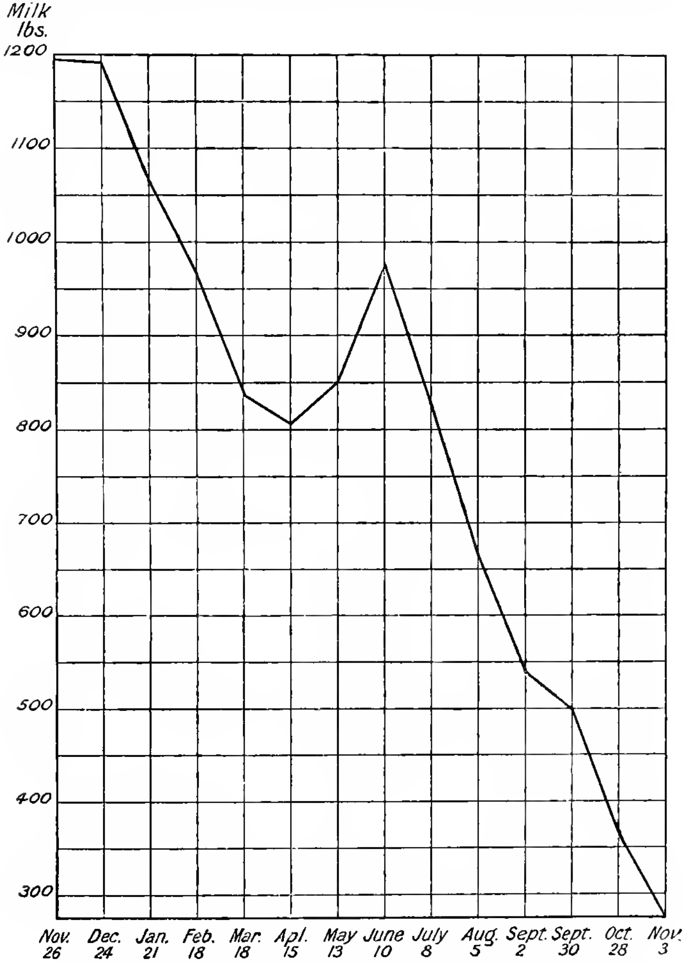

FIG. 12.

the graph shown in the illustration (Fig. 12). It represents the total yield of milk (in lbs.) of a cow at Reading College

Farm for each period of four weeks throughout the time of lactation. It will be seen that the yield diminishes steadily, almost from the first, until about the middle of April, when she was turned out to grass. The effect of this change of food was to produce a sudden and considerable increase in the yield. The maximum increase was attained in the period ending June 10, after which it again declined owing to the gradual advance in the stage of lactation.

It is, of course, impossible to base any general inferences on the record of a single cow. The following figures relating to a herd of twenty-three cows, which were turned out to grass on May 1, are perhaps more convincing, if not quite so striking.

Total Daily Yield of Twenty-three Cows.

Date	April 29.	April 30.	May 1.	May 2.	May 3.
Yield (gals.) . . .	48½	48½	45¾	50¼	51½

The influence of the food on the quality of the milk is less certain. The evidence is somewhat conflicting; but there appears to be no doubt that liberal feeding, when it does not increase the total yield, tends to raise the percentage of solids in the milk. On the other hand, when the rations are not adequate to the quantity of milk produced—especially if they are deficient in protein—the percentage of solids is generally diminished. The variation in the quality of milk which can be effected in this way is, however, confined within very narrow limits.

The majority of practical men seem to believe that the food has no effect at all upon the ratio of fat to non-fatty solids; and the physiological evidence regarding the processes by which milk is formed (p. 286) tends to confirm this view. Still it is found that liberal feeding, *i.e.* rations which tend to increase the total yield of milk, or the percentage of solids in it, tends also to increase the ratio of fat to non-fatty solids. According to Fleischmann,[1] "animals whose milk is absolutely richer in fat, at the same time yield milk relatively richer

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[1] "The Book of the Dairy."

in fat." In proof of this statement he quotes the following data:—

	Fat.	Total solids.	Fat per cent. of total solids.
(143) Dutch cows . . .	3·226	11·913	27·08
(100) German cows . .	3·242	11·953	27·13
(24) Shorthorn cows . .	4·518	13·948	32·39
(24) Jersey cows . . .	4·908	14·596	33·62

It is very difficult to obtain information on these points because the amount of total solids, and more particularly the amount of fat, in milk are affected by many other conditions, and to a much greater extent than by the influence of the food.

The food of the animals also affects the composition of the milk solids in a qualitative as well as in a quantitative sense. In general, foods which are rich in fats tend to produce butter of a softer character than those which are richer in protein and carbohydrates. Adolf Mayer declares that when the food is very rich in carbohydrates, the butter fat contains a larger amount of volatile acids (p. 43). The fat of the food does not pass directly into the milk, but it has a very direct influence on the texture of the butter. Cotton cakes, for example, are said to produce harder butter than linseed or rape cakes. The views of practical men on this subject are shown below:—

FOODS WHICH TEND TO PRODUCE

Hard butter.	Soft butter.	Norma or medium butter.
Peas. Beans. Clovers. Vetches. Maize. Cotton cake. Palmnut cake. Cocoanut cake.	Pasture grass. Wheat bran. Linseed cake. Rape cake. Earthnut cake.	Wheat. Barley. Rye. Malt coombs. Oats.

Cost of Production.—The influence of the food on milk production, when regarded from a commercial standpoint, requires careful consideration. The question is a difficult one to investigate theoretically, owing to the fluctuation in the prices of the feeding stuffs and of the milk produced. The case of a farmer who grows hay, roots, corn, and beans, and sells the milk at 6*d.* or 8*d.* per gallon, is very different from that of a town dairyman who has to purchase everything, but who realises from 1*s.* to 1*s.* 4*d.* per gallon for his produce. The following calculations are to be regarded merely as illustrating the method of investigation.

The more important points to be considered are: (1) Each cow requires a certain ration simply for maintenance, whether she produces milk or not; (2) additional food is required for milk production; (3) the larger the yield, the greater is the amount of additional food required, both absolutely and relatively.

If the amount of additional food required for milk production were directly proportional to the yield—or even approximately so—it is obvious that a yield of two gallons would afford a much larger profit than a yield of one gallon, and so on, because the cost of the maintenance ration must be added to that of the additional food in both cases. But this is not so. The second gallon costs more to produce it than the first, and the cost of production of each successive gallon increases progressively. A point must ultimately be reached, therefore, beyond which any further increase in the yield would cease to be profitable. An example will make this clear.

For simplicity, the maintenance ration may be supposed to consist entirely of hay, of which 19 lbs. would be required for a cow of 1000 lbs. live weight. If this fodder can be bought or produced for 65*s.* per ton, the cost of the maintenance ration would be 6½*d.* per head per day.

Let it be further supposed that the additional food for milk production consists of a mixture of decorticated cotton cake and maize, and that each of these substances costs £8 per ton. Two parts of cake to one of maize would give about the right proportions of nutrients. From these data the following results can be deduced :—

Yield of milk assumed . . .	1 gal.	2 gals.	3 gals.	4 gals.
Food for milk production . .	2·4 lbs.	5·32 lbs.	8·6 lbs.	12·65 lbs.
Cost of food for milk production	2*d.*	4½*d.*	7½*d.*	10¾*d.*
Cost of maintenance ration . .	6½*d.*	6½*d.*	6½*d.*	6½*d.*
Total cost of food	8½*d*	11*d.*	1*s.* 2*d.*	1*s.* 5¼*d.*
Average cost of food per gallon of milk	8½*d.*	5½*d.*	4¾*d.*	4¼*d.*

If the milk were sold at 7*d.* per gallon the margin of profit (price realised minus cost of the food) would be as follows :—

Yield of milk per cow . . .	1 gal.	2 gals.	3 gals.	4 gals.
Value of milk at 7*d.* per gallon	7*d.*	1*s.* 2*d.*	1*s.* 9*d.*	2*s.* 4*d.*
Cost of production (food) . .	8½*d.*	11*d.*	1*s.* 2*d.*	1*s.* 5¼*d.*
Margin of profit (gross) . . .	−1½*d.*	3*d.*	7*d.*	10¾*d.*

At the prices assumed, a yield of 1 gallon would result in a dead loss of 1½*d.* per day. When other expenses are added, it will probably be found that there would be little or no margin of profit when the yield is less than 2 gallons per head. Of course, if a higher price be put on the milk or a lower price on the hay, the result would be different. Probably no one who paid £3 5*s.* per ton for hay would sell milk at 7*d.* per gallon. If a farmer valued his hay at that price he would be making a profit on that, if not on the milk.

Some authorities put the cost of winter keep for cows in full milk as low as 9*d.* per head per day; others put it at about 1*s.*, and some even as high as 1*s.* 3*d.* per head per day. The differences in these estimates are to be attributed mainly to the differences in the prices assumed for the feeding stuffs, rather than to any divergence of opinion regarding the quantity or quality of the rations required.

Recent investigations [1] on this subject at sixty-six farms in

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[1] "Report on the Cost of Food in the Production of Milk." By James Macintosh, South Eastern Agricultural College, Wye.

Kent, embracing over two thousand cows, showed that the average cost of the rations used was 1*s*. $2\frac{3}{4}$*d*. per head, and that the average yield of milk was about $2\frac{1}{4}$ gallons. The average cost of the food was, therefore, about 7*d*. per gallon of milk produced. Practical experts have expressed the opinion that considerable economy might be effected at some of these farms.

It will be remembered that the formula used to calculate the rations required by cows is based upon what may be called the natural yield of the animals under the circumstances of the moment. It has been said, however, that the yield can be increased to a certain extent by making still further additions to the rations. This has been denied, but it is probably true nevertheless. The amount of food required to produce such an increase is, however, greatly in excess of that calculated by the formula, and the cost of production is, therefore, much greater.

The yield of any cow shows a constant tendency to decline owing to the gradual advance in the stage of lactation, and farmers and dairymen under contract to supply certain quantities of milk are naturally often tempted to try to force up the yield to the utmost limit of the cow's capacity. But if it be true, as stated, that this can only be done at much greater expense, it is clear that the process cannot be pushed very far without seriously diminishing the profits. There is reason to believe that it is sometimes overdone. It would be cheaper and, therefore, more profitable to regulate the rations according to the natural yield of milk to which the formula applies; and if this yield is not sufficient for the purpose, to bring in another cow.

Rations.—The following are examples of rations actually used by farmers. The average live weight of the cows was about 12·00 lbs. and the maintenance ration required would, therefore, be about 40 kt.

Ration I.

Feeding stuffs.	Thermic energy.	Digestible protein.	Non-n. nutrients as starch.
	Kt.	Lbs.	Lbs.
16 lbs. Meadow hay	41·92	0·73	—
4 ,, Oat straw			
20 ,, Swedes			
3 ,, Decort. cotton cake	1·30	1·78	4·09
2 ,, Oats			
2 ,, Beans			
2 ,, Bran			
	43·22	2·51	4·09

This ration contains just about the right amount of coarse fodder for maintenance, leaving the whole of the more expensive, concentrated food available for milk production. In this respect the ration is an economical one; but a further slight saving might have been effected by substituting some of the cheaper foods, *e.g.* rice meal, molasses, etc., for some of the cake or beans, as the proportion of digestible protein is higher than is requisite. The actual yield is not known, but the ration, as it stands, is sufficient for about 2½ gallons per day.

Ration II.

Feeding stuffs.	Thermic energy.	Digestible protein.	Non-n. nutrients as starch.
	Kt.	Lhs.	Lbs.
4½ lbs. Meadow hay	40·79	0·43	—
10½ ,, Oat straw			
3 ,, Wheat straw			
56 ,, Mangels			
2½ ,, Egyptian cake	1·10	1·16	4·95
1¾ ,, Bombay ,,			
2½ ,, Gluten feed			
1¾ ,, Bastol			
	41·89	1·59	4·95

In this ration about half the roots as well as the hay and straw are required for maintenance. This leaves the balance of the roots and all the cake and meal available for milk production—an economical arrangement. The average yield of milk was 2·14 gallons, for which 0·92 lb. of digestible protein and 3·7 lbs. of "starch" would be required. The excess of protein in the concentrated food is just sufficient to counterbalance the deficiency in the maintenance ration, but the considerable excess of non-nitrogenous nutrients would be wasted.

Ration III.

Feeding stuffs.	Thermic energy.	Digestible protein.	Non-n. nutrients as starch.
	Kt.	Lbs.	Lbs.
6 lbs. Meadow hay	39·38	0·36	—
6 ,, Oat straw			
56 ,, Mangels			
34 ,, Brewer's grains	1·88	1·36	3·93
	41·26	1·72	3·93

The average yield of milk was 2·03 gallons, for which 0·87 lb. of digestible protein and 3·45 lbs. of "starch" would be required. After allowing for the deficiency of protein in the maintenance ration, there still remains a slight excess of this ingredient, and also of non-nitrogenous nutrients. On the whole, this ration must be considered very satisfactory, both from a chemical and a pecuniary standpoint; but for other reasons practical men consider it inadvisable to feed such a large quantity of wet grains.

The next two rations represent the opposite extremes of bad management. One is utterly inadequate, and the other contains nearly twice the amount of nutrients required. Both rations were actually used by practical farmers.

Ration IV.

Feeding stuffs.	Thermic energy.	Digestible protein.	Non-n. nutrients as starch.
	Kt.	Lbs.	Lbs.
18 lbs. Mangels	33·10	0·69	—
8 ,, Oat straw			
2½ ,, Pea straw			
8 ,, Wet grains			
2 ,, Oats			

The total available energy of this ration is not sufficient for the maintenance of the animals. The yield of milk was just over one gallon, and this must have been produced at the expense of the tissues. No record of the actual weight of the animals is available, but they presented all the appearance of being starved, and must very soon have gone dry.

RATION V.

Feeding stuffs.	Thermic energy.	Digestible protein.	Non-n. nutrients as starch.
	Kt.	Lbs.	Lbs.
25 lbs. Meadow hay . .	35·13	1·00	2·08
84 ,, Cabbages . . .	4·74	3·61	12·48
40 ,, Wet grains . . .			
3 ,, Linseed cake . .			
	39·87	4·61	14·56

In this ration the hay alone is more than sufficient for maintenance. The balance of the hay and all the other food is, therefore, available for milk production. The average yield of milk was only about 3 gallons, for which 1·4 lbs. of digestible protein and 5·6 lbs. of "starch" would be required. This ration must, therefore, be condemned as badly balanced and extravagantly excessive. It would not, of course, be entirely wasted, as some of the excess would be stored up as fattening increase. There is, unfortunately, no record of the live weight of the animal, but it is not generally considered advisable to fatten cows in milk.

RATION VI.

Feeding stuffs.	Thermic energy	Digestible protein.	Non-n. nutrients as starch.
	Kt.	Lbs.	Lbs.
16 lbs. Pea straw . .	23·04	0·64	—
16 ,, Oat straw . . .	23·40	3·61	11·19
9 ,, Meadow hay . .			
35 ,, Mangels			
9 ,, Decort. cotton cake .			
6 ,, Treacle			
	46·44	4·25	11·19

This ration is extremely faulty in every respect. The amount of coarse fodder is nearly twice as much as is required for maintenance. The balance, no doubt, is available for milk production, but such foods are neither suitable nor economical for this purpose. The total amount of nutrients, and especially of protein, is excessive. If all the hay and a third of the cake were eliminated from this ration, it would still be sufficient for the maintenance of cows of 1200 lbs. live weight, and production of 4 gallons of milk per day.

The ration was used by an experienced farmer. He was under contract to supply a certain quantity of milk, and was afraid that if he reduced the rations the yield of milk would diminish. The facts came to the author's knowledge in connection with complaints regarding the quality of the milk. On examination the milk was found to contain 5·1 per cent. of fat, but in other respects it was quite normal.

In analysing rations from the point of view of efficiency and pecuniary economy, as above, the coarse fodder is first appropriated for maintenance, and any excess is treated as available for milk production. If the whole of the coarse fodder is insufficient, some of the more expensive concentrated food must also be appropriated for maintenance, and only the balance is treated as available for milk production. When the quantity of coarse fodder is sufficient, the whole of the concentrated food is thus available except what is spent on the work of digesting it. The thermic energy of this portion is, of course, added to that of the coarse fodder, but as it is usually very small it may be ignored in practice.

The thermic energy of the maintenance ration includes that due to oxidation of the digestible protein. The protein and non-nitrogenous nutrients which appear in the milk are not oxidised, and they are more conveniently considered apart.

CHAPTER XII

INCREASE

Increase.—In previous chapters it was assumed, for simplicity, that the live weight of the animal remained constant. Any system of feeding which resulted in a diminution of the weight would, of course, be unspeakably bad. We have, therefore, only to consider those circumstances and conditions under which it may increase. These are briefly, (1) pregnancy of females, (2) growth of young animals from birth to adolescence, (3) fattening of adults. The increase of weight of any given animal might of course be due to more than one of these causes; and it has to be kept in view that the animal might also be doing work or producing milk at the same time. In this way very complicated questions might, and do, sometimes arise. The most important is that of the fattening of young (growing) animals. It is convenient, however, for purposes of study, to consider each of the cases separately in the first instance. It is scarcely necessary to remark that the phenomena are not exactly the same for different kinds of animals—cattle, sheep, and pigs.

Any increase in the live weight of an animal indicates an addition to the mass of its body, *i.e.* of the quantity of matter in it, and the matter so added must be derived from the food and water consumed. The constituents of the maintenance ration are not available for this purpose, for they are all disposed of in other ways. The increase in live weight must, therefore, be derived from additional food added to the maintenance ration for the purpose.

The maintenance rations required by any given animal, under known conditions, can be approximately calculated by the formulæ (p. 128). In order to find out how much additional food is required for increase of any kind, obviously, the first step is to determine, as nearly as possible, the nature of the substances of which the increase is composed, and the amount of each constituent in it.

The method of investigation is, broadly, much the same in all cases, and may be illustrated as follows. The increase is always made up of substances which may be classed as water, ash, nitrogenous matter and fat; and, for the present, we need only concern ourselves with the last two. What we have to consider is the relative proportions and actual amounts of each.

Suppose that a calf at birth weighs 60 lbs., and that on analysis it is found to contain 16 per cent. of nitrogenous matter and 14 per cent. of fat, the remainder—70 per cent.—being ash and water. The total increase (60 lbs.) therefore contains 9·6 lbs. of the former, and 8·4 lbs. of the latter substance. As the average period of gestation is about 40 weeks—say 280 days—the nitrogenous matter is deposited at the average rate of 0·034 lb. per day, and the fat at the average rate of 0·03 lb. per day, *i.e.* about half an ounce per day in each case.

Again, suppose the calf to weigh 60 lbs. at birth, and to contain 9·6 lbs. of nitrogenous matter and 8·4 lbs. of fat as before; and further, that when it is one year old it weighs 700 lbs., and contains 18 per cent. of nitrogenous matter and 21 per cent. of fat. Then 700 lbs.—the total live weight of the yearling animal—includes [18 × 7 =] 126 lbs. of nitrogenous matter, and [21 × 7 =] 147 lbs. of fat. Deduct from these quantities, respectively, the amount of nitrogenous matter (9·6 lbs.) and of fat (8·4 lbs.) present in the calf at birth, and we get the amount of nitrogenous matter (116·4 lbs.) and of fat (138·6 lbs.) deposited in 365 days. From this it appears that the former substance is deposited at the rate of 0·32 lb., and the latter at the rate of 0·38 lb. per day.

Lawes and Gilbert's Investigations.—In the year 1849, Lawes and Gilbert commenced, at Rothamsted, a series of investigations upon the composition of the bodies of different kinds of farm animals under varying circumstances of age and condition, from the results of which they calculated, in a manner similar to that indicated above, the *composition of the fattening increase.* The data obtained in these classic researches are still regarded as the most reliable fundamental basis in all investigations of this kind. They are given in the table below.

CHEMICAL COMPOSITION OF THE BODIES OF FARM ANIMALS PER CENT. OF THE FASTED LIVE WEIGHT.[1]

Animal.	Fasted live weight.	Contents of stomach and intestines (moist).	Total dry substance.	Water.	Nitrogenous compounds (proteins).	Fat.	Mineral matter (ash).
	Lbs. Ozs.	%	%	%	%	%	%
Fat calf . . .	258 12	3·17	33·8	63·1	15·2	14·8	3·80
Half-fat ox . .	1232 0	8·19	40·3	51·5	16·6	19·1	4·66
Fat ox . .	1419 0	5·98	48·5	45·5	14·5	30·1	3·92
Fat lamb . . .	80 6½	8·54	43·7	47·8	12·3	28·5	2·94
Store sheep . .	97 10	6·00	36·7	57·3	14·8	18·7	3·16
Half-fat old sheep	105 1	9·05	40·7	50·2	14·0	23·5	3·17
Fat sheep . . .	127 2½	6·02	50·6	43·4	12·2	35·6	2·81
Extra fat sheep .	252 8	5·18	59·6	35·2	10·9	45·8	2·90
Store pig . . .	93 15	5·22	39·7	55·1	13 7	23·3	2·67
Fat pig . . .	185 0	3·97	54·7	41·3	10·9	42·2	1·65

ESTIMATED COMPOSITION OF THE FATTENING INCREASE PER CENT.

Oxen	—	—	75·4	24·6	7·69	66·2	1·47
Sheep . . .	—	—	79 9	20·1	7·43	70·9	1·60
Pigs	—	—	78·0	22·0	6·44	71·5	0·06

The two pigs actually analysed were from the same litter, and appeared to be very much alike in all respects. As it was impossible to ensure the same degree of correspondence in regard to sheep and oxen, it was considered advisable, in estimating the composition of the increase, to take the average weights of a large number of typical animals in the store and fat conditions, instead of the weights of the animals actually analysed. The analytical results seem to justify the assumption that they fairly represent the composition of the bodies of the animals in their respective conditions, and, therefore,

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[1] "Rothamsted Memoirs," vol. iii. p. 537.

that the weights of any animals in a similar condition may be applied to them.

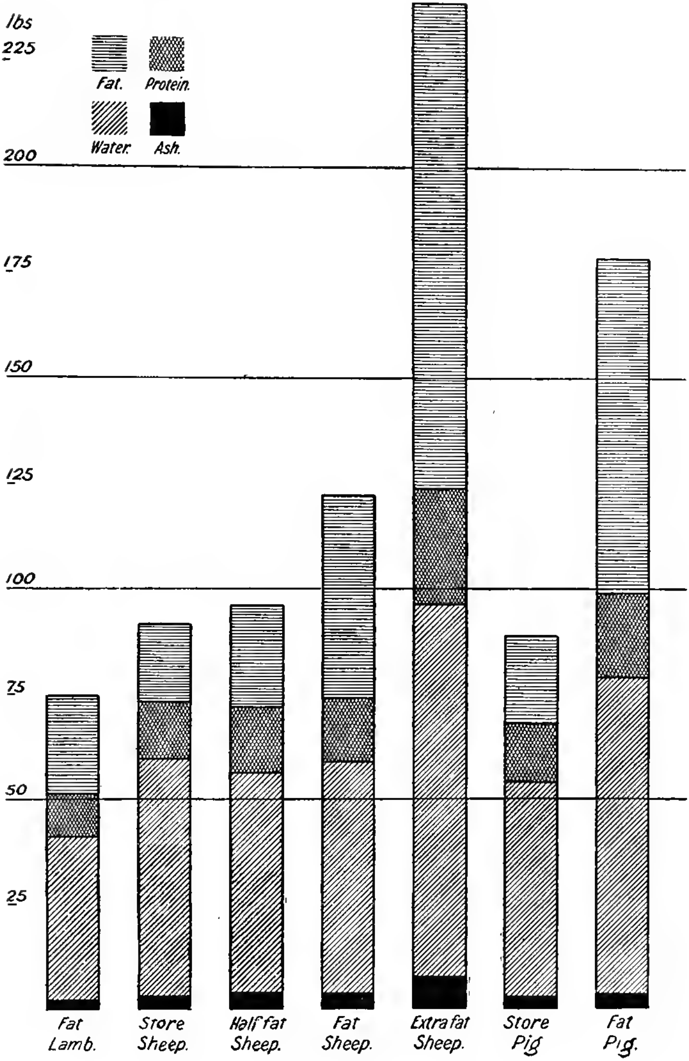
It will be seen that the bodies of adult fat animals contain a larger percentage of fat and a smaller percentage of all other constituents than those of similar animals in the lean or store condition. In fact, it appears as if the process of fattening consisted mainly in the replacement of water by fat. In their memoirs, Lawes and Gilbert express the opinion that, under certain conditions, this may actually occur. When the composition of the increase is considered, however, it will be seen that the amounts of these constituents are increased, not diminished; but as the fat is increased by two or three times as much as all the other ingredients together, the *relative proportions* of the latter are necessarily smaller.

In order to show what actually happens, the amounts of the contents of the stomachs and intestines were deducted from total percentages given in the tables, and the remainders —being the actual constituents of the bodies—were calculated to the original live weights of the animals minus these amounts. The results obtained are given in the table, and, for sheep and pigs, also in diagrammatic form (Fig. 13).

CHEMICAL COMPOSITION OF THE BODIES OF FARM ANIMALS, CALCULATED ON THE ORIGINAL FASTED LIVE WEIGHT MINUS THE CONTENTS OF STOMACH AND INTESTINES.

Animal.	Water.	Nitrogenous compounds (protein).	Fat.	Mineral matter (ash).	Total.
	Lbs.	Lbs.	Lbs.	Lbs.	Lbs.
Fat calf . . .	162·9	39·3	38·3	9·8	250·3
Half-fat ox . .	635·0	204·6	235·4	57·5	1132·5
Fat ox	645·6	205·7	427·1	55·6	1334·0
Fat lamb . . .	38·4	9·9	22·9	2·4	73·6
Store sheep . .	55·9	14·4	18·3	3·1	91·7
Half-fat old sheep	52·7	14·7	24·7	3·3	95·4
Fat sheep . . .	55·2	15·5	48·3	3·6	122·6
Extra fat sheep .	88·9	27·5	115·6	7·3	239·3
Store pig . . .	51·8	12·9	21·9	2·5	89·1
Fat pig . . .	76·4	20·2	78·1	3·0	177·6

On comparison of the half-fat ox with the fat ox, and the



lbs
225
200
175
150
125
100
75
50
25
Fat.
Protein.
Water.
Ash.
Fat Lamb.
Store Sheep.
Half fat Sheep.
Fat Sheep.
Extra fat Sheep.
Store Pig
Fat Pig.

FIG. 13.

store, half-fat and fat sheep, it will be seen that there is but little increase in the actual amounts of water, nitrogenous matter and ash, and that the increase of live weight consists almost entirely of fat.

In cases where the increase of live weight is more considerable, *e.g.* those of the extra-fat sheep, and the fat pig, the amounts of water and nitrogenous matter are also seen to be substantially increased. Judging by the mineral matter, it would appear that both animals had grown as well as fattened. A more marked change of the same kind is noticeable on comparison of the lamb and sheep and of the calf and ox.

We may take it, therefore, that fattening, *i.e.* the change from the store to the fat condition, as apart from growth, consists mainly in the deposition of fatty tissue. As a matter of fact, other experiments tend to show that the additional nitrogenous matter and water found in the fat animal are mainly in the blood, and very little, if any, in the permanent non-fatty tissue.

When a young animal grows, all the constituents are increased in quantity, both fat and non-fatty tissue being deposited. When an animal grows and fattens at the same time, both changes occur simultaneously. The amounts of all the constituents are increased, but the increase of fat exceeds that of the others.

The rate of increase in fattening depends largely upon the age and condition of the animals. It is much more rapid during the earlier than in the later stages. The weight of an animal which is growing as well as fattening naturally increases much more rapidly than that of one which has already attained its full growth. But apart from this, great differences are observed in the rate of fattening increase not only as between animals of different kinds and breeds, but even between individuals of the same parentage, under similar conditions as regards food, shelter, etc.

The data obtained or used in the Rothamsted experiments are of peculiar interest in this connection. Some of them are given in the following table.

Rate of Increase of Fattening Animals in Rothamsted Experiments.

Description and number of animals.	Duration of experiment.	Average per head.			
		Live weight.		Increase.	
		Original.	Final.	Total.	Daily.
	Days.	Lbs.	Lbs.	Lbs.	Lbs.
12 Heifers	132	1010·3	1272·8	262·5	1·99
50 Bullocks	166	1095·9	1429·4	333·5	2·00
36 Bullocks	187	1144·1	1514·8	370·7	1·98
46 Cotswold sheep	138	119·8	193·4	73·6	0·52
40 Leicester sheep	140	101·3	145·9	44·6	0·32
40 Hants Downs sheep	182	113·4	183·0	69·6	0·38
40 Sussex Downs sheep	182	88·0	140·7	52·7	0·29
1 Pig	70	103·0	191·0	88·0	1·26
24 Pigs	56	143·3	240·1	96·8	1·73
36 Pigs	56	141·8	228·4	86·6	1·54

In round numbers, the average rate of fattening increase for the smaller breeds of oxen is about 1½ lbs., and for the larger, up to 2 lbs. per day. The total gain may amount to about 30 per cent. of the original weight. In the case of sheep, the rate varies from about ½ to ¾ lb. per day, and the total gain from about 40 to 50 per cent. of the original weight. Fattening pigs increase at the rate of from 1¼ to 1¾ lbs. per day. The total gain varies from about 45 to 95 per cent.; the average may be put at about 60 or 70 per cent. of the original weight.

Taking the composition of the fattening increase as given in the table (p. 189), and the rate of increase as, for sheep ⅓ lb., for pigs 1½ lbs., and for oxen 2 lbs. per head per day, the data relating to increase of live weight may be summarised as follows :—

Increase due to	Constituents deposited daily.	
	Protein.	Fat.
	Lb.	Lb.
Pregnancy (cows)	0·034	0·03
Growth (calves)	0·32	0·39
Fattening (oxen)	0·15	1·32
,, (sheep)	0·024	0·23
,, (pigs)	0·10	1·07

These constituents are in all cases derived from the food, *i.e.* from additional food over and above what is required for maintenance. It is true that, in pregnancy, a fœtus might develop, and that a young animal might continue to grow even under conditions bordering on starvation, but there would be no increase in live weight. The fœtus could only develop at the expense of the pregnant animal, and a young one which became enlarged would necessarily become attenuated in corresponding degree. There can be no increase of any kind unless the animal takes in more than it gives out. It is obvious, therefore, that, in each case, the animal must receive, *at least*, enough food to supply the constituents deposited daily in addition to a sufficient maintenance ration; and it is desirable that such additional food should be of a readily digestible kind.

Pregnancy.—The additions to be made to the maintenance rations on account of pregnancy are so small, even in the case of large animals like cows, as to be practically negligible. The margin which should always be allowed over and above the theoretical minimum requirements would generally be more than sufficient to provide for this trifling increase. The question of pregnancy may, therefore, be dismissed without further consideration.

Growth.—The additions required to provide for growth are more considerable. Thus, in the case of calves growing, not fattening, at an average rate of 2 lbs. per day, the addition should comprise at least 0·32 lb. of protein and 0·95 lb. of starch or its equivalent in other nutrients. These are minimum quantities, and various considerations render it desirable that they should be increased.

It is found, for example, that when calves are fed entirely on milk, about 25 per cent. of the protein—the whole of which is digestible—is excreted in the fæces. This nitrogenous matter probably consists mainly of effete bowel membranes and digestive enzymes. The amount of digestible protein should, therefore, be not less than about 0·4 lb. The non-nitrogenous nutrients should also be increased to allow for what is expended in the digestion of the food. The additional food for growth should be of a readily digestible character and, therefore, as a rule, only slight additions would have to be made on this account. In general, 0·4 lb. of digestible protein and 1 lb. of digestible starch, or the equivalent of the same in other forms, will be sufficient for an increase of 2 lbs. live weight due to growth. This is expressed by the formula—

$$P = 0{\cdot}2\ I;\ C = 0{\cdot}5\ I$$

where P is the amount (lbs.) of digestible protein, C is the amount of digestible non-nitrogenous nutrients, reckoned as starch, and I is the increase (lbs.) due to growth per day.

These quantities of nutrients are, of course, to be given in addition to what is required for simple maintenance. The latter depends upon the size of the animals, and can be determined by the formulæ (pp. 128, 130). While the animals are still young the maintenance rations should not consist entirely of coarse fodders such as hay and straw; and quantities of the more readily digestible roots, cabbage, maize, etc., are generally substituted for a portion of the former. This, of course, does not affect the amounts of digestible nutrients required either for maintenance or growth; but any excess or deficiency in either portion of the total ration can be used to compensate deficiency or excess in the other.

For example, the maintenance ration for a calf of 300 lbs. live weight, calculated by the formula, is 15 kt. This could be obtained from $8\frac{1}{4}$ lbs. of hay, from 47 lbs. of swedes, or from 5 lbs. of hay and 18 lbs. of swedes. To whichever of these rations is selected there must be added the special food for growth; and as the ration, when it consists wholly or partly of swedes, will be deficient in protein, the allowance of cake must be increased. The following quantities would form a complete ration: 5 lbs. hay, 18 lbs. swedes, $1\frac{3}{4}$ lbs. linseed cake, and $\frac{1}{3}$ lb. middlings.

If it is desired to state the requirements of the animals in the form of a feeding standard, this can be done as follows:—At the same rate as for adult oxen, the allowance of protein for maintenance should be 0·23 lb., and 15 kt. corresponds to 4 lbs. of starch. Add 0·4 lb. of protein and 1 lb. of starch for growth, and the feeding standard becomes altogether 0·63 lb. of digestible protein and 5 lbs. of starch, *i.e.* for a calf of 300 lbs. live weight growing, not fattening, at an average rate of 2 lbs. per day.

As the animals grow bigger, the allowance for maintenance must be increased, and those which grow less or more rapidly should receive a smaller or larger allowance on this account. Calculated as above, the feeding standards for calves of different size, but growing at the same average rate, would be as follows :—

Live weight.	Digestible nutrients.	
	Protein.	Starch.
Lbs.	Lb.	Lbs.
300	0·63	5·0
400	0·70	5·9
500	0·78	6·6
600	0·85	7·5
700	0·93	8·2

The calculated quantities given above correspond closely with those recommended by various authorities as a result of direct experiment; but for reasons given elsewhere (p. 136) such feeding standards cannot be considered reliable. The custom of reckoning the amounts of nutrients required per 1000 lbs. live weight, instead of per head (as above), seems to be particularly objectionable in the case of young, growing animals.

In rearing young stock some farmers prefer to "do them well," *i.e.* to partially fatten them while they are growing. Others prefer to allow only for growth, and to postpone the fattening process entirely to a later stage. The relative economy of these two methods is discussed later on (p. 212). The fact is referred to here only because it probably accounts, to a large extent, for the apparent difference of opinion regarding the rations required by growing animals. The conclusions arrived at in this section are based upon the composition of the bodies of the full-grown animals in the store condition. The quantities given are, therefore, strictly those required for growth only, as apart from fattening.

Fattening.—It was shown (Chapter VIII.) that, under certain conditions, body fat can be formed from all or any of the digestible nutrients—fat, protein, and carbohydrates—of the food. The physiological heat values[1] of these constituents are 9·4 kt., 4·93 kt., and 3·76 kt. per lb., respectively. It might be expected that they would bear much the same relation as fat formers, *i.e.* that 2·5 lbs. of starch, and 1·9 lbs. of protein would each produce the same amount of body fat as 1 lb. of fat in the food. This expectation has been entirely justified as regards the former, but not as regards the latter.

Calculating from the chemical composition of the two substances, Henneberg inferred that 51·4 lbs. of fat could be formed from 100 lbs. of protein. This relation—commonly called Henneberg's number—was generally assumed in the older experiments. Further investigation has shown, however, that it is too high. Body fat is formed from the protein of the food only when the latter is present in excess of the requirements for other purposes. When the transformation does occur, a considerable part of the protein is oxidised, and not more than 39 parts of fat are formed from 100 parts of that substance, *i.e.* 2·56 parts of protein are required to produce the same increase as 1 part of fat in the food. These quantities—2·56 parts of protein, 2·5 parts of starch, and 1 part of fat are, therefore, said to be equivalent for the production of fattening increase. Put in the other way, 1 part of starch is equivalent to 0·4 part of fat, and 1 part of protein to 0·39 part of fat.

Referring to the composition of the fattening increase (p. 189), it will be seen that, on the average, it contains about 7 per cent. of protein and 70 per cent. of fat. It might be expected, therefore, that an allowance of 0·07 lb. of the former, and 0·7 lb. of the latter, in addition to an adequate maintenance ration, would be sufficient to provide for an increase of 1 lb. This is approximately true when the animals are in a very lean condition, but the rate of increase for food consumed gradually diminishes as the animals become fatter.

Experiments in the respiration chamber show that fattening

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[1] Some fats are of lower value (cf. Chapters IX. and XIII.).

animals generate more heat than those in store condition. The process of fattening apparently involves additional internal work, more food is oxidised, and the resulting energy appears as heat. The amount of the maintenance ration may, therefore, be somewhat reduced, or more readily digestible food may be substituted for a portion of it. Otherwise heat may be developed more rapidly than it is given off, and in hot weather the animals become uncomfortably warm, and the process of fattening is retarded.

On the average, oxen do not store up as body fat more than about 60 per cent. of the fat, or equivalent quantities of other nutrients, in the food. Sheep, apparently, store up more—probably about 75 per cent.—and pigs not less than about 90 per cent. In the case of pigs, the question is complicated by the fact that they are generally fattened while still growing. The rate of increase is, therefore, very rapid, but the composition of this increase is not exactly the same as that assumed above. It is probably true, however, that pigs store up a larger proportion of the nutrients of the food as true fattening increase than do the ruminants.

The amount of protein in the fattening increase is relatively small. If, however, the allowance of protein in the food were limited to what is actually stored up as such in the animal's body, the digestibility of the other nutrients would be depressed and waste of food would result. The minimum appears to be about 1 part of protein to 10 parts of non-nitrogenous nutrients reckoned as starch, *i.e.* about 2½ times the proportion in which it occurs in the fattening increase.

Fattening Oxen.—In the case of oxen, each pound of fattening increase, it is estimated (p. 189), contains 0·077 lb. of protein, and 0·66 lb. of fat. But as only 60 per cent. of the fat (or its equivalent) in the food is stored up as body fat, 1·1 lbs. of fat, or equivalent quantities of other nutrients, *e.g.* 2·75 lbs. of starch, are required to produce each pound of increase. To this must be added 0·08 lb. of protein, which is also retained as such, and an allowance of about 5 per cent. for loss in the work of digesting the food. Hence it appears that about 3 lbs. of total digestible nutrients, reckoned as starch, are required for each pound of fattening increase; and of this at least 10 per cent. (0·3 lb.) must be protein.

This may be expressed by formulæ as follows:—

$$N = 3I$$

$$P = \frac{N}{10} = 0{\cdot}3I \; ; \; C = \frac{9}{10}N = 2{\cdot}7I$$

N is the amount (lbs.) of total digestible nutrients, P is the amount (lbs.) of protein, C the amount (lbs.) of non-nitrogenous nutrients reckoned as starch, and I the total fattening increase (lbs.) per day.

The amounts of nutrients given above are for fattening only, as apart from growth, maintenance, etc. To deduce a feeding standard for fattening full-grown oxen, the nutrients of the maintenance ration must be added. For oxen of 1000 lbs. original live weight, increasing at an average rate of 2 lbs. per day, the feeding standard would be as follows:—

	Digestible Nutrients.	
	Protein. Lbs.	"Starch." Lbs.
For maintenance	0·75	8·4
,, fattening	0·60	5·4
Total	1·35	13·8

The results obtained above agree closely with those of other authorities, but they are open to the same objection as all other feeding standards (p. 136). These need not now be repeated, but it may be pointed out that the two fundamental considerations—the maintenance requirements and the rate of increase—by which they are determined vary independently of each other. As the live weight of the animal increases, a larger maintenance ration is required. As the animal gets fatter, a smaller proportion of the nutrients is stored up. The feeding standard should not, therefore, be the same throughout the fattening period. If the two portions are calculated by the independent formulæ from time to time, the matter adjusts itself automatically. For the reasons given above, however, the additions to the maintenance portion should consist of the finer, more readily digestible foods rather than of hay and coarse fodders.

Rations.—In compounding rations for fattening stock, the two portions are to be calculated separately, but it must be kept in view that any small excess or deficiency in one may be compensated in the other. The following simple ration would satisfy the chemical conditions in the case of an ox of 1000 lbs. live weight fattening at the average rate of 2 lbs. per day.

RATION I.

Feeding stuffs.	Maintenance.		Fattening.	
	Protein.	Th. energy.	Protein.	Starch.
	Lb.	Kt.	Lb.	Lbs.
20 lbs. Meadow hay . .	0·8	36·6	—	—
7 ,, Maize . . .	—	—	0·49	5·88
Requirements	0·7	35·0	0·60	5·40

The slight deficiency of protein in the fattening food is compensated by a slight excess in the maintenance portion. The amount of digestible non-nitrogenous nutrients in both is slightly larger than is required for a 2-lb. increase. This ration, however, would probably not be deemed quite suitable from a practical standpoint. It is too dry, and apt to prove binding. It should, therefore, be amended in the manner indicated in the following rations which have been used in practice. In the absence of exact information regarding the size of the animals, and the rate of increase, it is difficult to criticise them, but the salient points are easily discernible.

RATION II.

Feeding stuffs.	Maintenance.		Fattening.	
	Protein.	Th. energy.	Protein.	Starch.
	Lb.	Kt.	Lb.	Lbs.
12 lbs. Meadow hay . .	0·48	21·96	—	—
84 ,, Swedes 40 lbs. .	0·10	12·80	—	—
44 ,, .	—	—	0·11	2·92
4 ,, Linseed cake . .	—	—	1·00	2·24
Total . . .	0·58	34·76	1·11	5·16

In addition to the meadow hay, about 40 lbs. of roots are required for maintenance; the "starch" corresponding to the *dynamic* energy of the remainder is available for fattening. As a whole, the ration is not very well balanced; it contains a slight excess of protein, and a not inconsiderable deficiency of non-nitrogenous nutrients. This could be rectified by addition of ½ lb. of molasses or similar food.

RATION III.

Feeding stuffs.	Maintenance.		Fattening.	
	Protein.	Th. energy.	Protein.	Starch.
	Lb.	Kt.	Lbs.	Lbs.
10 lbs. Clover silage . .	0·22	4·66	—	—
10 ,, Oat straw . . .	0·10	15·60	—	—
10 ,, Meadow hay . .	0·40	18·30	—	—
5 ,, Linseed cake . .	—	—	1·39	2·13
5 ,, Maize	—	—	0·35	3·92
Total . . .	0·72	38·56	1·74	6·05

The proportions of fine and coarse fodders in this ration are very well adjusted. The only fault that can be found in regard to composition is the unnecessarily large amount of protein in the fattening portion. This would not be entirely wasted, but a slight pecuniary saving might be effected by using a larger quantity of maize and less cake.

RATION IV.

Feeding stuffs.	Maintenance.		Fattening.	
	Protein.	Th. energy.	Protein.	Starch.
	Lb.	Kt.	Lbs.	Lbs.
20 lbs. Oat straw . .	0·20	31·2	—	—
100 ,, Turnips { 20 lbs. .	0·05	4·8	—	—
80 ,,	—	—	0·20	4·00
5 ,, Linseed cake . .	—	—	1·25	2·79
Total . . .	0·25	36·0	1·45	6·79

It may be questioned whether it is wise to feed so large a quantity of watery food to fattening oxen; but judged by the amounts of nutrients, the ration is entirely satisfactory. About 0·5 lb. of protein in the fine foods must be credited to the maintenance portion to compensate for the deficiency in the latter; the remainder is ample, but not greatly excessive.

RATION V.

Feeding stuffs.	Maintenance.		Fattening.	
	Protein.	Th. energy.	Protein.	Starch.
	Lb.	Kt.	Lb.	Lbs.
15 lbs. Meadow hay . .	0·6	27·45	—	—
4 ,, Bran	0·4	9·84	—	—
2 ,, Oats	—	—	0·18	1·14
1 ,, Linseed cake . .	—	—	0·25	0·56
Total . . .	1·0	37·29	0·43	1·70

The meadow hay and bran together form a liberal, but not excessive maintenance ration; but the allowance of oats and bran is quite inadequate for fattening. The ration was used for cattle on board ship, and was probably not intended to improve their condition, but only to prevent it becoming impaired. For this purpose it is probably satisfactory.

Sheep.—The requirements of fattening sheep may be computed in a similar manner. Each pound of increase contains 0·71 lb. of fat and 0·074 lb. of protein. These ingredients are together equal to 1·86 lbs. of starch. There is some uncertainty regarding the amount of the nutrients that can be stored up as body fat by sheep, but there appears to be no doubt that it is greater than in the case of oxen. It is probably not less than 75 per cent., and at that rate, 2·48 lbs. of starch, or equivalent quantities of other nutrients, would be required. To this must be added a certain allowance for the work of digestion. For fine foods used in fattening this may be put, on the average, at about 5 per cent. The total amount of nutrients, reckoned as starch, required to produce an increase of 1 lb. live weight would, therefore, be 2·6 lbs. Of this amount at least a tenth (0·26 lb.) should, as before, be in the form of protein.

Expressed as a formula, this conclusion would read as follows:—

$$N = 2{\cdot}6I;\ P = 0{\cdot}1N = 0{\cdot}26I;\ C = 0{\cdot}9N = 2{\cdot}34I$$

N is the required amount (lbs.) of total digestible nutrients, I is the average daily increase (lbs.) of live weight, P is the minimum amount (lbs.) of protein, and C is the amount of non-nitrogenous nutrients reckoned as starch.

It will be seen, therefore, that the requirements of sheep—for fattening as apart from maintenance—are somewhat less than those of oxen, notwithstanding the rather larger proportion of fat in the increase. This of course results from the assumption, not hitherto proved, that sheep store up a larger proportion of the nutrients than oxen do.

If the average rate of increase in live weight be taken as one-third of a pound per day, the actual requirements of the animals for fattening would be 0·86 lb. of total nutrients; or counting the protein separately 0·09 lb. of digestible protein and 0·78 lb. of "starch" per head.

In order to express the total requirements in the form of a feeding standard it may be assumed that the sheep have an average live weight of 100 lbs. per head at the beginning of the fattening period. The maintenance requirements of animals (sheep) of this size were estimated at 4 kt., which is equal to 0·08 lb. of digestible protein and 0·95 lb. of starch. If the two quantities are now added together, the result is—

	Protein.	Starch.
For maintenance	0·08	0·95
,, fattening	0·08	0·78
Total feeding standard .	0·16	1·73

These quantities are per 100 lbs. live weight. If it is desired to make the feeding standard comparable with that for oxen and other animals, the amounts of nutrients should be multiplied by 10, so as to give quantities per 1000 lbs. live weight. This standard corresponds closely with those of Wolff, Kellner, and others, but it is open to the same objections as those previously considered.

In certain experiments at Woburn a number of sheep were fed for 112 days on rations consisting of ¼ lb. of meadow hay, 20 lbs. of swedes, and ¾ lb. of whole wheat. The average live weight of the animals at the beginning of the experiment was 119 lbs. and the average daily gain was 0·4 lb. per head. The requirements of the animals, calculated by the formulæ, were 4·52 kt. for maintenance, and 1·04 lbs. of total nutrients, reckoned as starch, for fattening. On analysis it will be seen that the ration provides almost exactly these quantities, but it contains less protein than is generally deemed advisable. Probably, however, most of the nitrogenous matter of the roots which is not true protein is suitable for the formation of digestive enzymes, and that is the chief function of the protein in the fattening portion of the ration.

ANALYSIS OF THE RATION.

	¼	lb.	Hay yields	0·46	4·46 kt. thermic energy.
20	12½	,,	Swedes yield	4·00	
	7½	,,	,, ,,	0·53	1·09 lbs. "starch."
	¾	,,	Wheat ,,	0·56	

The results of the experiment, therefore, afford strong confirmation of the theoretical considerations enunciated above.

The following rations which are given us having been used in practice may also be submitted to a similar analysis :—

	½	lb.	Meadow hay yields	0·91	4·11 kt. thermic energy.
15	10	,,	Swedes yield	3·20	
	5	,,	,, ,,	0·35	0·92 lb. "starch."
	½	,,	Undec. cotton cake yields	0·20	
	½	,,	Barley yields	0·37	

Assuming an average, original live weight of 100 lbs., and deducting the amount required for maintenance, the balance of the ration is sufficient for an average daily increase of 0·35 lb. The total amount of digestible protein (0·15 lb.) is just about right. This ration is, therefore, a suitable and economical one for sheep of the size and rate of increase assumed.

	1	lb.	Clover hay yields	1·83	3·99 kt. thermic energy.
10	6¾	,,	Swedes yield	2·16	
	3¼	,,	,, ,,	0·23	0·61 lb. "starch."
	½	,,	Linseed cake yields	0·38	

This ration is probably intended for sheep of smaller size. At all events, if all the hay and enough of the swedes are appropriated for the maintenance of sheep of 100 lbs. live weight, the balance of the ration is sufficient for an average daily increase of only 0·23 lb.

Sheep are perhaps more often fattened at pasture, but unless the pasture is exceptionally good — and the best pastures are not generally reserved for sheep—it is customary to give a certain allowance of cake or meal in addition. It is difficult to ascertain exactly what amount of grass sheep actually consume when grazing, but it is easy to calculate what they actually require. Assuming that the grass is of the average composition given in the tables, about 8 lbs. per day would be required for the maintenance of a 100-lbs. animal, and an additional 7 lbs. is required to provide for a daily increase of $\frac{1}{3}$ lb. If 1 lb. of undecorticated cotton cake were fed, only 4 lbs. of grass would be required for the remainder of the increase; or, adding the amount required for maintenance, about 12 lbs. in all, *i.e.* with 1 lb. of cake. Very different estimates of the amount of grass consumed are sometimes given, but in most cases they are merely guesses without foundation of any kind.

Fattening Pigs.—Owing to the physiological differences previously referred to, pigs are unable to utilise to advantage the coarse fodders that are suitable for the maintenance of ruminants. The notion that "pigs will thrive on anything"—kale runts and dishwater—is not founded on fact. They require finer, not coarser, foods than other animals, and are often fed entirely on a single food, such as barley meal.

The investigation of the requirements of pigs is complicated by the fact that they are generally fattened while still young. The food requirements for maintenance, growth, and fattening are all different, and should be investigated separately.

As pigs are rarely kept in store condition it is difficult to determine exactly what the maintenance requirements are. Sanborn's[1] experiments are almost the only available data on

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[1] Bul. 28, Missouri Agricultural College.

which to base an estimate. In these trials the animals were fed on wheat middlings, and the quantities of food were adjusted so as to keep them as nearly as possible without gain or loss of weight. The author has calculated the thermic energy of the food consumed and included the results with the other data given in the table below.

SANBORN'S EXPERIMENTS.

No. of pigs.	Average live weight.	Duration of trial.	Food consumed.		Total increase.	Thermic energy of food per head per day.
			Total.	Per cent. of live weight.		
	Lbs.	Days.	Lbs.		Lbs.	Kt.
3	48	21	63	2·1	1·5	3·00
6	172	18	352	1·9	20·0	9·75
6	173	10	172	1·7	3·0	8·85
12	175	28	1184	2·0	3·0	10·21

The required amounts of thermic energy calculated by the formula (p. 128) according to the size of the animals, are 4·19, 10·23, 10·26, and 10·35 kt. in the four cases respectively. The last case is probably the most reliable by reason of the larger size of the animals, the larger number under experiment, and the longer duration of the trial. It will be seen that the calculated requirements correspond fairly closely with the food actually consumed. In the first trial, the calculated amount is 25 per cent. higher than that observed; but it should be kept in view that pigs of that age would, under ordinary circumstances, be growing rapidly, and as they did not gain appreciably in weight they must have been losing in condition. On the whole, it appears that the maintenance requirements of pigs in terms of thermic energy differ from those of oxen only in proportion to the size of the animals, and that the formula previously given is applicable.

The results of numerous trials at the various experiment stations in America have been collated by Henry.[1] These may be used to investigate the requirements for growth and

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[1] "Feeds and Feeding."

fattening. The more important data are summarised in the following table:—

No. of trials.	No. of animals.	Average live weight.	Food consumed.		Average daily increase.	
			Per head.	Per cent. of live weight.	Per head.	Per cent. of live weight.
		Lbs.	Lbs.		Lbs.	
41	174	38	2·23	5·95	0·76	2·00
100	417	78	3·35	4·32	0·83	1·06
119	495	128	4·79	3·75	1·10	0·86
107	489	174	5·91	3·43	1·24	0·71
72	300	226	6·57	2·91	1·33	0·59
46	223	271	7·40	2·74	1·46	0·55
19	105	320	7·50	2·35	1·40	0·44
5	36	378	8·52	2·25	1·98	0·52
5	36	429	8·18	1·91	1·71	0·39
2	18	471	10·00	2·12	1·77	0·37

The last three lines of this table are, perhaps, less reliable than the others, owing to the comparatively small numbers and exceptional character of the animals concerned. On the whole, however, the data are as regular as could be expected, and the general trend of the results is clear. It will be seen (1) that the total increase is greatest in the case of the largest animals, (2) that the increase per cent. of the live weight gradually diminishes as the size of the animals increases, (3) that it approaches the point of constancy—about 0·4 per cent. of the live weight, *i.e.* a little higher than in the case of sheep —when the animals are, presumably, full grown.

In the case of full-grown animals, the whole of the increase must be due to fattening; and it is safe to conclude that the more rapid increase of the younger animals is due, in part, to growth. If we assume the same rate of fattening—0·4 per cent. of the live weight—in all cases, the increase due to growth can be calculated by the formula—

$$G = I - F$$

G is the increase due to growth, apart from fattening, F the increase due to fattening, apart from growth, and I is the total increase.

The assumption made above appears to be justified in the cases under consideration, but it does not hold good in all. Pigs might be fattened more or less rapidly. They might even be kept strictly in store condition throughout the whole period of growth. In any case, there will be no true fattening until the requirements for growth have been satisfied.

Judging from the data given above, and others of a similar kind, it appears that the maximum increase due to growth in very young pigs is about 2 per cent. of the live weight per day. But the rate of increase due to growth gradually diminishes as the animals grow bigger, and when they are full grown it is zero. Upon further consideration of the data it appears that the actual increase due to growth in any given case may be found, approximately, by the formula—

$$G = \frac{2(M' - M)}{3M'}$$

M is the actual live weight of the animal, and M′ the maximum live weight in the store condition.

Since $$F = I - G$$

therefore $$F = I - \frac{2(M' - M)}{3M'}$$

If the value of G, according to the formula, be determined for each case given in the tables and added to F reckoned as 0·4 per cent. of the live weight, it will be found that the sum of the two numbers corresponds very closely, in most cases, with the total increase actually observed. For these calculations, the live weight of the full-grown animals in the store condition (M′) was taken as 400 lbs.; but in some it must have been larger, and, possibly, in others it was less. For reasons given above, however, the value of F must, in general, be taken as the difference between the total increase and that due to growth.

When the amount and composition of both parts of the increase are known, the amounts of nutrients required to produce them may be estimated by the methods previously described. To avoid unnecessary repetition these may be briefly stated as follows :—

(1) For growth, $N = 0{\cdot}7G$; $P = \frac{N}{5}$; $C = \frac{4N}{5}$

(2) For fattening, $N = 2F$; $P = \frac{N}{10}$; $C = \frac{9N}{10}$

N is the amount (lbs.) of total nutrients required, P is the protein (lbs.), and C the non-nitrogenous nutrients as starch (lbs.). As before, G and F are the amounts (lbs.) of the increase due to growth and fattening respectively.

Substituting the values previously obtained for G and F, we get—

$$(1)\quad N = \frac{1{\cdot}4(M' - M)}{3M'}$$

$$P = \frac{0{\cdot}28(M' - M)}{3M'};\quad C = \frac{1{\cdot}12(M' - M)}{3M'}$$

$$(2)\quad N = 2\left\{1 - \frac{2(M' - M)}{3M'}\right\}$$

$$P = 0{\cdot}2\left\{1 - \frac{2(M' - M)}{3M'}\right\};\quad C = 1{\cdot}8\left\{1 - \frac{2(M' - M)}{3M'}\right\}$$

The total amounts of nutrients required by young pigs for increase (growth and fattening jointly), as apart from maintenance may therefore be expressed by the following formulæ[1] :—

$$P = \left[\frac{0{\cdot}28(M' - M)}{3M'} + 0{\cdot}2\left\{1 - \frac{2(M' - M)}{3M'}\right\}\right]$$

$$C = \left[\frac{1{\cdot}12(M' - M)}{3M'} + 1{\cdot}8\left\{1 - \frac{2(M' - M)}{3M'}\right\}\right]$$

The calculated amounts of protein and of non-nitrogenous nutrients required for maintenance, growth, and fattening, when added together, agree fairly closely with the amounts of digestible nutrients in the food actually consumed. It follows that, in these cases, practically the whole of the nutrients in

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[1] N.B.—These formulæ are capable of further simplification.

the fattening portion of the ration—except what was spent in the work of digestion, and this has been allowed for in the calculation—must have been stored up as fattening increase.

In the Rothamsted experiments the pigs were allowed an unlimited amount of food, consisting chiefly of barley meal, and they fattened more rapidly than those in the experiments described above. The amounts of food required, calculated on the same basis as the latter, were much less than was actually consumed. It is evident, therefore, that in the Rothamsted experiments the whole of the digestible nutrients was not stored up. Apparently only about 60 per cent., *i.e.* about the same as in oxen, was stored up as fattening increase.

If both sets of experiments are to be relied upon, it seems clear that the percentage of the digestible nutrients that pigs can store up as body fat depends to some extent upon the amount of food consumed in proportion to the live weight of the animal.

An important question of pecuniary economy arises in this connection. If the animals store up a larger proportion of the nutrients when the quantity of the food is duly limited than when it is not, it might appear at first sight that the former is the more economical method of feeding. It must be remembered, however, that when the food is limited, the rate of increase is slower, and the portion of the food which is dissipated in simple maintenance is consumed daily. The data at hand are not sufficient for the solution of this problem on a chemical basis.

The difficulties revealed above may possibly suggest that it is the method of investigation that is at fault, and that, in this case, at least, it would be better to adhere to the older method of feeding standards. That recommended by Kellner for full-grown pigs gives about 3 lbs. of digestible protein and 28 lbs. of total digestible non-nitrogenous nutrients reckoned as starch, per 1000 lbs. live weight, corresponding to the following quantities per head (calculated by rule of three).

Live weight.	Digestible protein.	Digestible "starch."
Lbs.	Lbs.	Lbs.
300	0·9	8·4
400	1·2	11·2
500	1·5	14·0

The quantities of food corresponding to the amounts of nutrients are much greater than were used in the American experiments. The rate of increase to be expected is not given; but as the animals are "full grown" the whole—whatever it may amount to—must be regarded as true fattening increase. It is only necessary, therefore, to deduct the due allowance for maintenance in order to find how much is available for fattening in each case. Assuming that the whole of the nutrients in the balance (beyond what is required for maintenance) is to be stored up as body fat, this balance would correspond to a fattening increase of 2·2 lbs., 3·1 lbs., and 6·3 lbs. per day in the three cases respectively. If only 60 per cent. were stored up, it would correspond to 1·32 lbs., 1·86 lbs., and 3·78 lbs. of fattening increase per head per day in the three cases respectively. The feeding standard in question is, however, for the first stage only; smaller quantities are recommended for the second and third stages. Still it is evident that the last-mentioned quantity is excessive.

General.—In all experiments on fattening, it is found that the rate of increase is more rapid in the earlier stages and gradually diminishes as the animals approach the "finished" condition. It may be supposed that for each individual there is a stage beyond which it could not be fattened any more; and as this point is arrived at gradually, the return—in the shape of fattening increase—for food consumed must gradually become less and less. Each successive pound of fattening increase costs more to produce than the preceding one. It is not, therefore, profitable to continue the process of fattening beyond a certain stage.

In some parts of the country, oxen are kept strictly on maintenance rations until they are fully grown, and the fattening process is not begun until this stage is achieved. In other districts the custom is to feed the calves more liberally from the time they are weaned, so as to fatten them gradually all the time they are growing. There may be practical reasons which render one or other of these courses the more expedient in particular cases; but from a purely theoretical standpoint, the advantage, as regards pecuniary economy, rests with the former. A fat animal gives out more heat than a lean one, and, therefore, requires more food to maintain it in that condition. If the rations of a fat beast were reduced to what is required for simple maintenance in the store condition, it would go back, *i.e.* it would gradually lose weight and become thin again.

The fact that a young animal puts on weight more rapidly than an adult—on which the whole argument seems to be based—is entirely beside the question. The extra weight which a young animal puts on is due to growth, not fattening, and there is nothing to show that more food is required to produce a pound of true fattening increase in adults than in young animals.

The case of fattening lambs, calves, or other growing animals, may be investigated in the manner described above for pigs.

AVERAGE COMPOSITION[1] OF FEEDING STUFFS.

Food.	Total Constituents.					Digestible Nutrients.			Albuminoid ratio in digestible matter.	Starch value for fattening.	Assumed average price.			Number of food units.	Price per unit (n).	
	Total dry matter.	Crude protein.	Crude fat.	Soluble carbohydrates.	Crude fibre.	True protein.	Fat.	Carbohydrates and fibre.			Per ton.					
	Per cent.	Per cent.	Per cent.	Per cent.	Per cent.	Per cent.	Per cent.	Per cent.			£	s.	d.		s.	d.
Oil Cakes—																
Cotton cake, decort.	92	41	9	26	8	34	8·5	20	1·25 : 1	71	8	0	0	151	1	0½
,, undecort. Egyptian	88	22	5·5	34	20	15·5	5·25	20	2·00 :	40	6	0	0	103	1	2
,, undecort. Bombay .	88	20	4·5	35	22	14	4	21	2·25 :	37	5	10	0	96	1	1¾
Linseed cake . .	88	30	10	34	9	25	9·5	32	2·25 :	76	9	0	0	134	1	4
Rape cake. . . .	90	32	10	29	11	22	8	24	2·00 :	61	5	10	0	134	0	10
Sesame cake . .	90	40	12·5	21	7	34	11	14	1·25 :	75	7	12	0	152	1	0
Earthnut cake . .	89	46	10	36	5	40	9·5	20	1·25 :	79	8	12	0	148	1	2
Palm-nut cake . .	90	17	10	36	22	14	9·5	36	4·00 :	72	6	5	0	103	1	1
Cocoanut cake . .	89	22	10	23	15	17	9·5	39	3·75 :	78	7	10	0	116	1	3½
Soybean cake .	88	43	7	27	5	34	6·5	21	1·00 :	68	8	0	0	152	1	0½
Oily Seeds—																
Soybeans . . .	89	36	17	26	5	28·5	15·5	20	2·00 :	82	—			158	—	
Linseed . . .	91	23	36	23	6	17	34	21	5·50 :	119	17	10	0	170	2	0¾
Pulse Grains—																
Peas . .	86	23	1·5	54	6	17	1	53	3·25 :	70	12	9	0	115	2	2
Beans	86	25	1·5	48	7	19	1·25	48	2·75 :	67	9	14	0	114	1	8½

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[1] Crowther.

AVERAGE COMPOSITION OF FEEDING STUFFS—*continued.*

Food.	Total Constituents.					Digestible Nutrients.			Albuminoid ratio in digestible matter.	Starch value for fattening.	Assumed average price.	Number of food units.	Price per unit. (*n*).
	Total dry matter.	Crude protein.	Crude fat.	Soluble carbohydrates.	Crude fibre.	True protein.	Fat.	Carbohydrates and fibre.					
	Per cent.	Per cent.	Per cent.	Per cent.	Per cent.	Per cent.	Per cent.	Per cent.			Per ton. £ s. d.		s. d.
Cereal Grains—													
Wheat	87	12	2	69	2	9	1·25	65	7·50 :	73	8 17 6	104	1 8½
Barley	86	10	2	67	5	9	1·75	64	9·75 :	74	8 15 0	97	1 9½
Oats	87	12	6	55	10	9	5·25	45	6·50 :	63	8 6 6	103	1 7¼
Rye	87	11·5	2	70	2	9	1	65	7·50 :	72	7 0 0	104	1 4
Maize	89	10·5	5	70	2	7	4·5	68	11·25 :	84	7 15 0	100	1 5
By-Products, etc.—													
Pollards (middlings)	88	15	3·5	62	5	12	3	56	5·25 :	74	7 0 0	108	1 3½
Sharps	88	15	4·5	57	8	11	3·5	50	5·25 :	58	6 3 0	106	1 2
Bran	87	14	4	56	9	10	3	45	5·25 :	47	5 0 0	101	1 0
Rice meal	90	12	12	50	8	6	10	42	11·00 :	70	6 0 0	110	1 1
Malt	92	10	2·5	68	8	6	2	63	11·25 :	70	11 13 0	99	2 4¼
Malt dust (coombs)	90	23·5	2	44	12·5	11·5	1·5	39	3·75 :	40	5 10 0	108	1 0¼
Brewer's grains (wet)	25	5·5	2	12	4·5	4	1·5	10	3·50 :	15	0 18 0	31	0 7
,, ,, (dry)	90	20	7	42	16	14	6	33	3·50 :	50	5 10 0	108	1 0¼
Gluten meal	90	38	4	45	2	33	3·5	42	1·50 :	77	8 2 6	150	1 1
Gluten feed	90	26	3	53	6	21	2·5	52	2·75 :	74	6 5 0	125	1 0
Locust beans	86	6	1·5	70	6	3·5	1	70	20·00 :	73	6 10 0	89	1 5½
Molasses (treacle)	78	10	—	60	—	—	—	55	—	48	4 18 0	85	1 2

Coarse Fodders—													
Meadow hay (good)	86	12	3	42	22	5	1·3	49	8·50 :	35	3 10 0	79	0 10½
,, (medium)	84	10	2·5	42	26	4	1	41	11·00 :	31	3 5 0	73	0 10½
,, (inferior)	84	8	2	38	33	2·5	0·5	34	14·00 :	18	2 10 0	63	0 9½
Clover hay (average)	84	13	2·5	37	25	5·5	1·5	38	7·50 :	31	4 0 0	76	1 0½
Straw, pea	86	9	1·5	34	35	3·5	0·75	32	9·75 :	15	2 10 0	60	0 10
,, bean	82	8	1	31	36	3·25	0·5	36	11·50 :	19	2 10 0	53	0 11¼
, wheat	86	3	1·25	37	40	0·25	0·5	34	71·00 :	12	2 10 0	48	1 0½
,, barley	86	3·5	1·5	38	38	0·5	0·5	40	83·00 :	19	2 10 0	50	1 0
,, oat	86	3·5	2	38	37	1	0·5	39	40·00 :	19	3 0 0	52	1 1
,, rye	86	3	1·25	33	44	0·5	0·5	35	73·00 :	11	2 10 0	44	1 1½
Green Fodders—													
Pasture grass	20	3	0·75	10	5	1·5	0·5	11	8·25 :	12	—	19	—
Clover (green)	19	3·5	0·75	8	5	2	0·5	9	5·25 :	10	—	19	—
Vetches ,,	16	3·5	0·5	6	5	2	0·25	7	4·00 :	8	—	16	—
Lucerne ,,	24	4·5	0·75	9	7	2	0·5	9	5·25 :	10	—	22	—
Cabbage ,,	15	2·5	0·75	7	2	1·5	0·5	7	5·50 :	9	—	15	—
Rape ,,	14	2 75	0·75	6	3	1·5	0·5	6	5·00 :	8	—	15	—
Roots—													
Turnips	9·5	1	0·25	6	1	0·25	0·1	6	25·00 :	6	0 8 0	9	0 10½
Swedes	11·5	1·25	0·25	8	1·5	0·25	0·1	8	33·00 :	7	0 10 0	12	0 10
Mangels	12	1·25	0·25	9	1	0·1	0·1	9	92·00 :	7	0 12 0	13	0 11
Carrots	13	1·25	0·25	9·5	1·5	0·5	0·1	10	21·00 :	9	—	13	—
Sugar beet	25	1·25	0·25	20	2	0·25	0·1	20	81·00 :	15	1 0 0	24	0 10
Potatoes	25	2	0·25	21	1	0·1	0·1	19	192·00 :	19	3 0 0	27	2 2½
Milk—													
Whole milk (cows)	12·5	3·5	3·75	4·75	—	3·25	3·75	4·75	4·25 :	16			
Separated milk	9	3·75	0·1	5	—	3·5	0·1	5	1·50 :	8			
Whey	7	1	0·25	5	—	—	0·25	5	5·50 :	6			

PART III.—FEEDING STUFFS

CHAPTER XIII

VALUATION OF FEEDING STUFFS

Constituents of Feeding Stuffs.—All estimates of the value of feeding stuffs, whether for agricultural or commercial purposes, *i.e.* the nutritive or the pecuniary values, are based ultimately on the composition as determined by chemical analysis. Even when the object is to determine the thermic or dynamic value of a substance, it is generally easier to do this by calculation from the composition than by direct estimation.

The results of chemical analyses of feeding stuffs are generally expressed in percentages as follows :—

(1) Albuminoids (or crude protein).
(2) Crude fat (or ether extract).
(3) Soluble carbohydrates (or nitrogen free extract).
(4) Crude or woody fibre.
(5) Moisture.
(6) Ash (or mineral matter).

The figures for albuminoids or crude protein are obtained by simply multiplying the percentage of nitrogen by the factor 6·25 (cf. p. 67). It includes any amides or other nitrogenous compounds which may be present; and for this reason, some writers prefer to call it the total nitrogenous matter. The seeds of plants, *e.g.* cereal grains, oil cakes, etc., contain little if any amides. Practically the whole of the nitrogenous matter in these products is true protein. The vegetative organs, especially roots, *e.g.* turnips, contain varying amounts of non-protein nitrogenous compounds, and the difference between the total nitrogenous matter and true protein in these cases is more considerable.

The soluble carbohydrates include the sugars, starch, and mucilaginous substances, and possibly some of the cellulose—all, in fact, of the dry substance except ash, fat, and nitrogenous matter that can be extracted by boiling with dilute acids and alkalis. It is for this reason that it is often referred to as nitrogen free extract. This term is, perhaps, not entirely satisfactory, but at least it is not open to the same objections as the other. Starch, for instance, is not soluble in water. The figures for the soluble carbohydrates are generally obtained by difference, *i.e.* by subtracting the sum of the percentages of the other constituents from 100.

The crude or woody fibre, or ligneous tissue as it is sometimes called, is the combustible residue which remains after extraction of the fat, soluble carbohydrates, and nitrogenous matter. It was originally supposed that this residue would represent the indigestible non-nitrogenous substance of the food; but modern experiments have shown that in the bowels of the animals—especially of ruminants—it is acted on by enzymes or bacteria, and is, in fact, digested to a more or less considerable extent. The whole of this fibrous material belongs to the carbohydrate group just as truly as the starch or sugars, and evidence has been obtained to show that any part of it that is digested has much the same nutritive value. The process of digestion of the fibre, however, involves the expenditure of a considerable amount of energy, and its presence therefore tends to lower the dynamic value of the food as a whole, and when in considerable quantity it also lowers the digestibility of the other nutrients. All natural feeding stuffs, however, contain some fibre, and a certain amount of it is considered necessary, especially for ruminants which are well adapted for dealing with coarse, bulky fodders. The presence of hard, fibrous substances in the food ensures thorough mastication, and it probably stimulates the action of the bowels and keeps the food in a suitable mechanical condition during the process of digestion.

Some writers give the "total dry matter" instead of the amount of moisture. This, of course, comes to the same thing, as the total dry matter is obtained simply by deducting the percentage of moisture from 100.

The percentage of ash or so-called mineral matter is of little importance because the proportion of these ingredients in all natural feeding stuffs is more than sufficient to provide for the requirements of the animals in this respect. The percentage of ash is, therefore, sometimes omitted from a statement of the composition of feeding stuffs. But if the percentages of total dry matter, and of protein, fat, soluble carbohydrates and fibre are known, the percentage of ash can be inferred. By deducting the percentage of ash and moisture from 100 we get the amount of "dry organic matter."

Prescriptions for feeding farm animals generally show what amount of dry organic matter as well as what amounts of nutrients the rations should contain. In other words, they show the degree of concentration, as well as the amounts of the nutrients, that are suitable for the different kinds of animals. This, of course, is a matter of physiology rather than of chemistry, but it is one that must be taken into account in practical feeding. In short, the food of the animal must be suitable in kind as well as in quantity.

If the composition and the coefficients of digestibility of a food are known, the amounts of digestible nutrients and the thermic and dynamic values of the product can be easily calculated by the methods previously described. These data for all the commoner feeding stuffs are given in the tables (pp. 166, 213). It is obvious, however, that, so far as purchased foods are concerned, they will be of little use to a farmer who persists in buying "mixed meals" and "compound cakes" unless he knows exactly what they contain; and this is just the information he is not likely to obtain from the seller.

Starch Value.—The starch value of a food may be defined as the amount of starch that is equivalent to the total fat-forming power of all the nutrients in it. This definition contains no direct reference to the digestibility of the food, but such is clearly implied. The fat-forming power of any substance that is not digested or that is spent in the work of digestion is zero. The relative fat-forming power which Kellner ascribes to the several nutrients is as follows :—

1 lb. of digestible fat	in oily seeds and oil cakes	= 2·41	lbs.	of starch.
	in cereal and pulse grains	= 2·12	,,	,,
	in coarse fodders (hay, straw, etc.)	= 1·91	,,	,,
1 lb. of digestible carbohydrates and fibre		= 1·00	,,	,,
1 lb. of digestible protein		= 0·94	,,	,,

The starch value of a food is, therefore, determined by multiplying the percentages of the digestible nutrients by these factors respectively, and deducting from the sum of the products a certain percentage which represents the amount spent on the work of digestion. This amount, of course, depends upon the kind of food. It is simply the percentage difference between the thermic and dynamic values of the food. It may be found by deducting the figures given in the fifth column of the tables (p. 166) from 100. The same result is obtained by multiplying the sum of the products by the numbers given and dividing by 100. The final result is called the "starch value" or "starch equivalent" of the food.

For example, the starch value of a sample of bran was determined as follows :—

Digestible nutrients.	Per cent.		Factor.		Starch value.
Protein	10	×	0·94	=	9·40
Fat	3	×	2·12	=	6·16
Soluble carbohydrates and fibre .	45	×	1·00	=	45·00
					60·56
Deduct 23 per cent. for work of digestion					13·93
Total starch equivalent of the food					46·63

or (*vide supra*) 60·56 × 0·77 = 46·63.

This means that 100 lbs. of bran is equivalent to, *i.e.* has the same fattening power as, 46·63 lbs. of pure starch.

Coarse fodders are not suitable or economical for fattening, and if the maintenance rations are considered separately, as recommended, the marked inferiority of the fat in hay and straws may be disregarded. At any rate, it is unnecessary to employ factors calculated to the second decimal place. For practical purposes, the mean value (2·3) may be used for the fat in all concentrated foods, and the protein may be reckoned equal to its own weight of starch. The starch equivalent of concentrated foods may therefore be calculated simply by adding the percentages of digestible protein, carbohydrates, and fibre to 2·3 times the digestible fat, and then, as before, making the necessary correction for what is spent in the work of digestion. Thus, in the case of bran, the calculation would be $\{10 + 45 + (3 \times 2{\cdot}3)\} \times 0{\cdot}77 = 47{\cdot}66$.

In order to utilise the starch equivalents of the foods to advantage, it is necessary to know the requirements of the animals in the same terms; and it was shown in Chapter XII. how these can be estimated. The term "starch equivalent" was not employed, but it will be seen, on reference, that the amounts of nutrients mentioned are in effect starch equivalents. It was shown that oxen can form, at most, about 0·6 lb. of body fat from 1 lb. of digestible fat, or equivalent quantities of other nutrients, in the food; but that sheep and pigs store up a larger proportion. The requirements of these animals, in terms of starch equivalents, are therefore less than those of oxen for a given increase in live weight. This, however, does not affect the determination of the starch equivalents of the foods or the application of the same. There is no reason to believe that there is any difference in the relative fattening power of the several nutrients, though they have not the same absolute power, for all animals.

The starch values of the foods are not empirical numbers. They are exact[1] scientific data, and afford a reliable estimate of the fat-forming powers of the different foods. So far as it relates to fattening—as apart from maintenance—the system has withstood all criticism, and has proved useful in practice.

For example, if it be known that the starch value of maize is 86 per cent., *i.e.* 0·86 per lb., and that the requirements of

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[1] The factors employed may call for revision or confirmation (cf. p. 121), but the soundness of the method is not open to question.

oxen, in these terms, are 6 lbs. of starch equivalent, the quantity of the food required can be ascertained by a simple calculation. Thus, $6 \div 0{\cdot}86 = 7$ lbs. is the quantity. Of course, if the food does not contain the necessary amount of protein, the balance must be derived from other sources; and in that case the rations must be compounded in the manner described in Chapter XIV.

It was pointed out in connection with the system of "feeding standards," referred to in previous chapters, that confusion must result if the thermic value of one food be added to the dynamic value of another; and that the difficulty is not overcome by expressing these values in terms of equivalent amounts of starch or other nutrient. This, however, does not apply to the starch values. The amount spent in the work of digestion is deducted in all cases. The results are therefore strictly comparable and can, if necessary, be added together. Feeding standards expressed in terms of starch equivalents are not, therefore, open to the same objections as those which show merely the total amounts of digestible nutrients required.

It should be recognised, however, that the system of starch equivalents has limitations. These have not always been properly appreciated, and the practical advantages appear to have been overestimated. It has been said, for instance; (1) that the starch value sums up all the properties of a food and expresses them by a single number; (2) that it forms the only reliable basis for the comparison of foods of different kinds; (3) that any two foods can be substituted for each other in the proportion of their starch equivalents without altering the nutritive value of the ration as a whole.

It may be pointed out, however, (1) that two numbers are always required—one for the protein and one for the non-nitrogenous nutrients; and in the system of starch equivalents, a third—the amount of total organic matter—must also be known; (2) foods of different kinds cannot be compared on any basis whatever without reference to the purpose for which they are to be used, and those which have the highest starch values are not in all cases the most suitable or economical; (3) the starch equivalent of meadow hay is about thirty, and that of oats about sixty, but 2 lbs. of the former cannot be substituted for 1 lb. of the latter in the rations of working horses.

The system of starch equivalents is based upon the relative fattening powers of the several nutrients. It is, therefore, applicable, strictly, only to rations for fattening. When applied—as it has been—to rations for work, milk production, and maintenance, the system becomes purely empirical, and certain precautions must be observed in using it.

Apologists have urged that no considerable error is involved if the starch values of the foods are used in computing the rations for work. This, as it happens, is true; but it is true only because such rations need not, and as a rule do not, contain a large amount of protein. According to Kellner, the relative fattening powers of protein and starch are as 0·94 to 1. As a source of dynamic energy, they stand in the relation of 4·93 to 3·76 (p. 123), *i.e.* 1·3 to 1. If, therefore, a large amount of protein were involved, the error would be considerable.

The converse of the above statement, viz. that no considerable error is involved if the dynamic values of the foods are used in computing rations for fattening, is necessarily true in the same degree. This close correspondence, of course, arises from the fact that, except as regards protein, the fattening powers ascribed to the nutrients bear practically the same relation as the dynamic values of the same. In fact, if the dynamic values of the foods are divided by that of starch (3·76), the figures obtained are approximately the starch values, except in the case of foods rich in protein. The dynamic values of the foods may, therefore, be used instead of the starch equivalents for comparison of nutritive values, and for most other purposes; and they are probably more reliable.

The advisability of applying the system of starch equivalents to the case of rations for milk production is questionable. Such rations necessarily contain a large amount of protein, of which the larger part ultimately appears, as such, in the milk. The protein is not oxidised, like that in rations for work, nor is it stored up as body fat, like that in rations for increase. Any excess of protein, beyond what is required for maintenance and what appears as such in the milk, may be converted into fat and carbohydrates. For this purpose it is approximately equivalent to an equal weight of starch. The whole of the protein, however, is included in the starch equivalent on this basis, whereas the larger part of it is disposed of in other ways. The requirements of the animals for milk production, in terms of starch equivalent, are, therefore, purely empirical numbers.

The disadvantages of the system of starch equivalents are, perhaps, most conspicuous in connection with its application to the case of maintenance rations. The value of a food for this purpose bears no direct relation to its fattening power. It depends upon the total amount of thermic energy obtainable from the food. The starch equivalent, however, does not represent the whole of this energy. The amount expended on the work of digestion is deducted because it is not available for fattening. But it is all available for maintenance; it is ultimately transformed into heat within the animal's body and helps to maintain its temperature. Thus, the maintenance ration for oxen is given as 6 lbs. starch equivalent per 1000 lbs. live weight. It was previously shown that about 35 kt. of thermic energy are required. There is an apparent discrepancy between the two statements, for 6 lbs. of pure starch yield, on oxidation, only 22·6 kt.; 9·3 lbs. would be required to produce 35 kt. The difference (3·3 lbs. of starch) represents the amount which, it is estimated, is spent on the work of digestion.

Since a certain amount is deducted in calculating the starch equivalent from the rations, the same amount must be added again when the process is reversed. In practice the difficulty is overcome by artificially reducing the estimate of the animal's requirements in terms of starch equivalent as shown above. Thus the starch value of hay is 31 per cent., *i.e.* 0·31 per lb., and as the maintenance requirements are given 6 lbs. of starch equivalent, the amount of hay required is [6 ÷ 0·31 =] 19·3 lbs. (cf. p. 139). The result, it will be seen, is practically the same as that calculated directly from the thermic energy of the food. That is because, in stating the requirements of the animal as 6 lbs. of starch equivalent, it is assumed that the maintenance rations always consist of hay or other coarse fodder, of which about 35 per cent. is spent on the work of digestion. But if the fodder actually used were of a less or more readily digestible kind, the result would be wrong unless a corresponding alteration were made in the estimate of the animal's requirements.

For example, 7 lbs. of maize and 50 lbs. of wheat straw respectively are equal to 6 lbs. of starch equivalent, but the quantities required to produce 35 kt. of thermic energy are 10·6 lbs. of the former and 26·3 lbs. of the latter. These are, perhaps, extreme cases. They were selected merely to illustrate the point above referred to. As a matter of fact, neither of these foods would, by itself, form a suitable maintenance ration for oxen.

In order to ensure that the foods selected shall be of the digestibility assumed in the estimate of the animal's requirements, a further statement is necessary showing, within certain limits, the amount of total organic matter in the food. Such a statement would rule out both of the foods previously mentioned. The importance of this datum, however, is often overlooked, and rations calculated from the starch equivalents alone are, therefore, sometimes erroneous and apt to prove misleading.

The rations of an animal must always include a certain allowance for maintenance, and an additional quantity for any work, milk, or increase produced. When the nutrients in both portions are expressed in terms of starch equivalents, they can be added together, and the whole stated in the form of a feeding standard. As, however, the starch equivalents for maintenance, work, and milk production are purely empirical and of somewhat doubtful value, it does not appear that such feeding standards are very reliable. They are also open to question on other grounds. On the whole, the author prefers to adhere to the methods previously recommended, viz. (1) to determine the maintenance ration from the thermic values of the foods, (2) to determine the rations for work from the dynamic values, (3) to determine the rations for milk production from the amounts of digestible protein and non-nitrogenous nutrients, (4) to determine the rations for fattening only from the starch equivalents. In each case the amounts are to be calculated separately according to the formulæ given for the purpose—not from feeding standards. The actual foods can, of course, be mixed together if deemed advisable on practical grounds.

In all cases care must be taken to ensure that the calculated quantities of food contain the required amounts of protein. When starch values are used, the protein is often overlooked or counted twice over. Such mistakes should not be attributed to any defect in the system, but rather to misapprehension on the part of those who employ it. At the same time, a system which readily lends itself to such mistakes must be deemed something less than perfect.

Nutritive Ratio.—In feeding for any specific purpose—maintenance, work, milk production, or increase—certain minimum amounts of digestible protein and non-nitrogenous nutrients are required, and these bear a certain definite ratio to each other in each case. If there be a deficiency of either kind of nutrient, the object of the feeding—whatever it may be—will not be satisfactorily accomplished. If there be more than is required of either kind of nutrient, the excess of that one may be wasted. Excess of protein, it is true, can perform most of the functions of the non-nitrogenous nutrients. It has approximately the same value as an equal weight of starch, but it is much more expensive. It is not desirable, therefore, on pecuniary grounds to give any considerable excess of protein.

The ratio of non-nitrogenous to nitrogenous nutrients in any food is called the "nutritive" or "albuminoid ratio" of the food. The contracted form, N-ratio, is often used. In order to determine this ratio, the non-nitrogenous nutrients must all be expressed in terms of one of them—starch. The amount of fat must therefore be multiplied by a factor which represents the value of the fat as compared with starch. The factor commonly used is 2·3; but in more exact calculations it should be 2·5 for oily seeds and cakes, and 2·2 for hay, straw, and coarse fodders generally. The intermediate number may be used for cereal and other grains.

The following example will serve to illustrate the method of working out the nutritive ratio of a food (bran) from the given data :—

	Total nutrients.		Digestibility coefficients.		Factor.		
Fat	4	×	0·75	×	2·3	=	6·9
Soluble carbohydrates . .	56	×	0·80			=	44·8
Fibre	9	×	0·20			=	1·8
Total non-nitrogenous nutrients as starch .							53·5
Protein	14	×	0·75			=	10·5

The ratio is, therefore, 53·5 to 10·5, or 5·1 to 1.

The ratio of the total protein to non-nitrogenous nutrients without reference to their digestibility, is of no value whatever.

A low N-ratio, say 5 to 1, is generally described as close or narrow; and higher ratios, say 10 to 1, are said to be wide.

The N-ratios of the foods are of considerable importance in judging of the suitability of the food for any specific purpose, also whether one food can be used to replace another, and, if so, in what relative quantity. They are used also in some of the calculations involved in compounding rations from two or more different foods.

Pecuniary Values.—There is no direct relation between the market prices of feeding stuffs and their agricultural (nutritive) value. The former is regulated, like that of all commodities, in accordance with the laws of supply and demand. The latter depends upon the amounts and digestibility of the nutrients. It is true, in general, that there is a greater demand for those foods which are of greater nutritive value, but the price, it has been said, depends not on this alone, but also, in part, upon the supply. Thus it happens that one food may be much cheaper or dearer than another even at the same price. Farmers, therefore, would be well advised, when purchasing feeding stuffs, to consider what amounts of digestible protein and of thermic or dynamic energy—according as the food is intended for maintenance or production—they can obtain in the various foods on the market for a given sum of money.

It is almost superfluous to say that this is rarely or never done. For one thing, the sellers will not, as a rule, consent to dispose of the goods on this basis. The prices of home-grown products—hay, cereals, etc.—vary according to "quality" so far as it can be determined by inspection—colour, smell, hardness. This, however, is often more a matter of vague sentiment or local prejudice than of nutritive value. In the case of the more highly concentrated and more expensive foods—cakes, meals, etc.—the "quality" is generally decided mainly by the composition, *i.e.* the total percentages of crude protein, fat, and soluble carbohydrates.

To say that the prices of the several nutrients vary in different foods is only to repeat that some foods are cheaper than others for equal amounts of the corresponding ingredients; moreover, the prices fluctuate from time to time and place to place. The *relative* values (prices), however, it may be assumed, remain constant, and are the same for all foods. They can only be very roughly evaluated, but it is found that, on the average, the relative prices per pound of crude protein and crude fat are about the same; that of the soluble carbohydrates is relatively less, about two-fifths of the price of the others. This may be expressed in the form of an equation as follows:—

$$s = n(2{\cdot}5\text{P} + 2{\cdot}5\text{F} + \text{C})$$

where s is the price, in shillings, per ton, P, F, and C are the percentages of crude protein, fat, and soluble carbohydrates respectively, and n is a number which is different for each food, and which varies according to the state of the market.

The sum of the terms within the bracket $(2{\cdot}5\text{P} + 2{\cdot}5\text{F} + \text{C})$ is called the number of "food-units." Since $s = n$ (food-units), therefore $n = \frac{s}{\text{food-units}}$. In a word, n is the price per unit. It roughly expresses the *relative* pecuniary value of the different foods. The following example illustrates the method of computing the number of food-units and (n) the price per unit in a meal sold at £5 10*s.* per ton (= 110*s.*):—

Nutrients.	Per cent.		Factor.		Food-units.
Crude protein . . .	12·5	×	2·5	=	31·25
Crude fat	6·6	×	2·5	=	16·50
Soluble carbohydrates	57·9	×	1·0	=	57·90
	Total.				105·65

$n = 110 \div 105{\cdot}65 = 1{\cdot}04$ shillings.

The following examples show the variation in the price per unit in some of the common feeding stuffs :—

Feeding stuffs.	Assumed average.				Calculated average.	
	Price per ton.	Composition per cent.			Number of units.	Price per unit (n).
		Protein.	Fat.	Carbohyd.		
	£ *s.* *d.*					
Linseed cake . .	9 0 0	30·0	10	34	134·00	1·35
Decort. cotton cake .	8 0 0	41·0	9	26	151·00	1·06
Wheat bran . . .	5 0 0	14·0	4	56	101·00	0·99
Brewer's grains (wet)	0 18 0	5·5	2	12	30·75	0·58
Oats	8 6 6	12·0	6	55	100·00	1·67
Hay	4 0 0	9·0	2	40	67·50	1·18

The term "food-units" is a misnomer. If it has any meaning at all it refers to the pecuniary, not the nutritive or "food" value of the substances. Feeding stuffs are, however, often compared on the basis of the number of food-units they contain, but such comparisons are not reliable. The nutritive value of 1 lb. of protein is not equal to that of 2½ lbs. of carbohydrates. So far as it performs similar functions it is probably not quite equal to 1 lb. of carbohydrate. When it performs different functions, as it should and usually does, there can be no comparison of nutritive values on any basis whatever.

For purely commercial purposes, however, if the number of food-units be accepted as the basis of pecuniary value, it can be used to advantage in several ways :

(1) If the price per ton and composition of any feeding stuff be known, the price per unit can be determined.

Conversely, if the price per unit be known, the price per ton of a sample of the same kind of material of any given composition can be determined. The former conditions are fulfilled when a feeding stuff is sold at a given price subject to a stated guarantee; and in the event of a difference between the analysis and the guarantee, the corresponding difference in price can be calculated. Example: a quantity of cake was sold at £8 10*s*. delivered and the cost of carriage was 10*s*. per ton, *i.e.* the price of the cake was £8 per ton. The other data were as follows:—

	Protein per cent.	Fat per cent.	Carbohydrates per cent.
Guaranteed	30	10	34
Found	25	9	40

The price per unit (*n*) according to the guarantee is 1·2; and the number of units found on analysis (125), multiplied by 1·2, gives £7 10*s*. per ton; add cost of carriage 10*s*. and we get £8 as the price (delivered) that should be paid.

(2) If the average price per ton and average composition of a feeding stuff be known, the *average* price per unit can be determined. Conversely, if the average price per unit be known, the *average* price per ton of a sample of any given composition can be determined; and by comparing this with the price asked, a purchaser can decide whether or not the same is reasonable.

(3) By comparing the average price per unit of different foods, a purchaser can form an approximate idea as to which will prove the most economical in a pecuniary sense. On reference to the table (p. 228) it will be seen that oats at 1·67 shillings per unit is the most expensive of the foods mentioned there, and that wet brewer's grains at 0·58 shilling per unit is the cheapest. The price per unit of linseed cake is nearly 30 per cent. higher than that of cotton cake.

Having compared the prices, the stockman has still to determine whether the cheaper foods are equally suitable for his purpose.

Classification.—Any classification of feeding stuffs, if it is to be of use for practical purposes, must be based on the chemical composition of the substance. This may be expressed in percentages of the several (digestible) nutrients, or as percentages of digestible protein and starch equivalents. The latter probably gives a truer view of the properties of the food, and it involves the use of a smaller number of separate figures which is a great advantage for purposes of comparison. It is, however, open to the objection that the protein is counted twice over, and it is a troublesome business to determine exactly and deduct that part of the starch equivalent which is due to the protein.

The author has found it convenient in practice to take the percentage of digestible protein and of digestible non-nitrogenous nutrients—the latter being all reckoned as starch (p. 172)—and from these data to plot the positions of the foods on a chart as shown in Fig. 14. For this purpose the protein is plotted on the abscissæ (vertical lines) and the non-nitrogenous nutrients on the ordinates (horizontal lines). Consequently, the greater the percentage of protein in a food the higher up will be its position on the page, and the greater the percentage of non-nitrogenous nutrients the further to the right.

Three diagonal lines are draw from the point of origin representing ratios of 2 to 1, 4 to 1, and 6 to 1 respectively. The chart, therefore, shows the nutritive ratios as well as the percentages of digestible protein and non-nitrogenous nutrients; and it is possible to compare any one food with another, or all together, at a glance.

On reference to the figure it will be found that several natural groups can be distinguished as follows:—

(1) The succulent green fodders (grass, etc.) and roots forming a close constellation[1] in the south-west corner. These contain less than 5 per cent. of protein and less than 20 per cent. of non-nitrogenous nutrients.

(2) The dry coarse fodders (hays and straws) containing less than 6 per cent. of digestible protein and from 35 to 45 per cent. of digestible non-nitrogenous nutrients. This can be subdivided into *(a)* cereal straws and *(b)* hays and leguminous

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[1] In order to compare these foods with each other they should be plotted separately on a larger scale as in the N.E. corner of the chart.

NATURAL CLASSIFICATION OF FEEDING STUFFS.

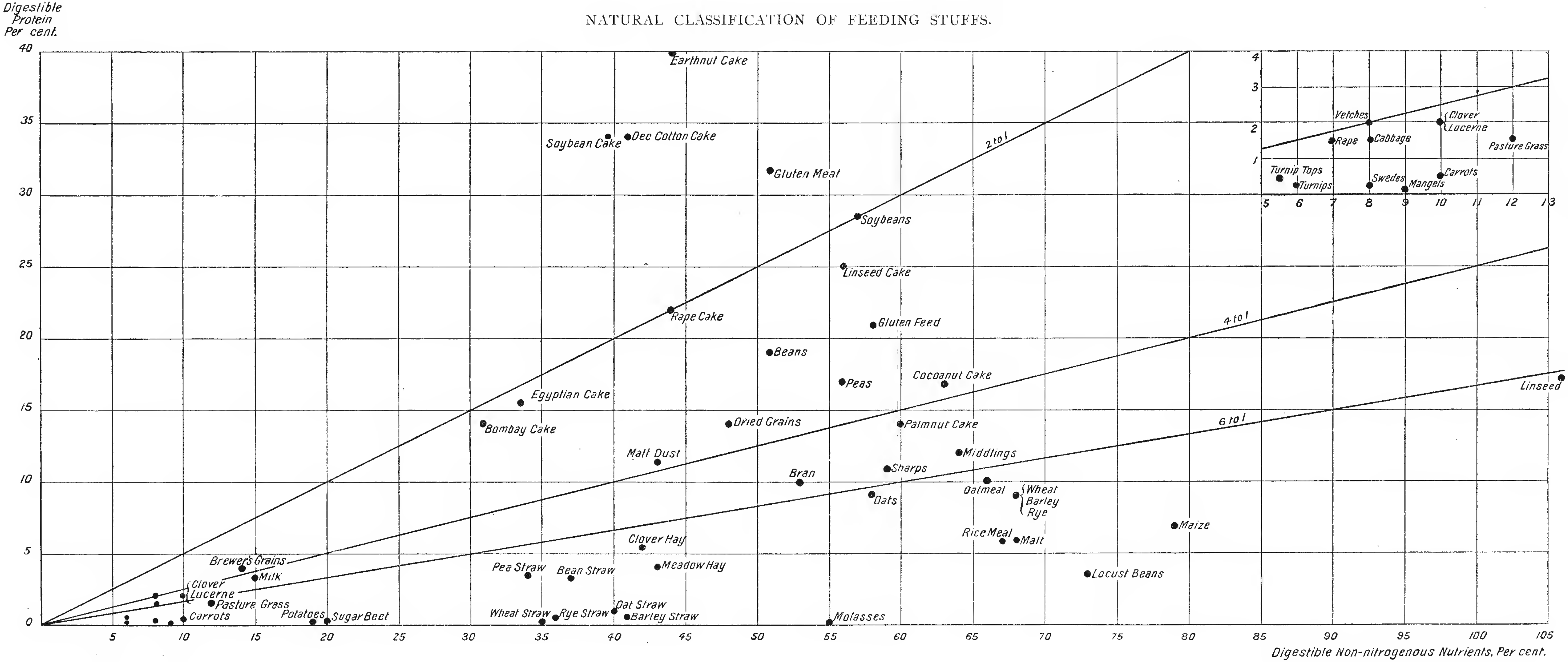

FIG. 14.

[*To face p.* 230.

straws. These sub-groups are broadly distinguished by the difference in the amount of protein.

(3) The more widely scattered group of concentrated foods, all of which contain either more than 12 per cent. of digestible protein, or more than 50 per cent. of digestible non-nitrogenous nutrients. In this division also several sub-groups of foods, of more or less similar composition, can be made out as follows:—

(*a*) Very highly concentrated substances with a nutritive ratio of less than 2 to 1, including earthnut cake, soya cake, decorticated cotton cake, and gluten meal.

(*b*) Concentrated foods with a N-ratio of from 2 to 1 to about 4 to 1. This group might be arbitrarily divided into one including soybeans, linseed cake, rape cake, and gluten feed, and another including beans, peas, dried grains, malt dust, cocoanut cake, palmnut cake, and the two varieties of undecorticated cotton cake.

(*c*) The cereal grains, wheat, barley, rye, oats, and their products, pollards, sharps and bran, and maize and rice meal. All these have a N-ratio of about 6 to 1 or less.

The pure oils, *e.g.* codliver oil, linseed, locust beans, and molasses all lie outside the natural groups mentioned above.

It will be seen, therefore, that these natural groups correspond with the ordinary agricultural classification of feeding stuffs. This may be rendered as follows:—

CLASSIFICATION OF FEEDING STUFFS.

I.—Succulent and watery foods.
    1. Roots and tubers.
    2. Herbaceous (green) fodders—grasses, clovers, vetches, cabbages, silage, etc.
II.—Coarse, bulky dry fodders.
    1. Hays.
    2. Leguminous straws.
    3. Cereal straws, chaff, husks, etc.
III.—Concentrated foods.
    1. Seeds—cereals, pulse, and oily seeds.
    2. Oil cakes, compound cakes, and meals.
    3. Commercial by-products, *e.g.* from milling, brewing, starch, and sugar industries.
IV.—Animal products, *e.g.* meat meals, milk, etc.

CHAPTER XIV

COMPOUNDING RATIONS

Problems.—It is obvious that a knowledge of the various matters discussed in previous chapters will be of little practical or theoretical advantage unless the actual foods can be so arranged as to conform to any standard that may be set up. Suppose, for example, that it is desired to feed an animal at the rate of 6 lbs. of starch (or the equivalent of the same) and 1 lb. of digestible protein per day; on looking through the tables giving the composition of the foods probably none will be found that contain the nutrients in exactly that proportion (6 to 1).

On reference to the chart (p. 230), we can readily discover which, if any, of the foods have a nutritive ratio nearest to that required. Of those represented, oats, green clover, and lucerne all lie fairly close to the 6 to 1 ratio line, and any one of these might be considered near enough for practical purposes in this respect. Assuming that a suitable food having the desired N-ratio were available, it would be a simple matter to calculate what quantity of it should be used.

A very similar case arises when it is desired to change the food of an animal without altering the amounts of nutrients in the ration. If, for example, beans were to be used in place of oats, consider what quantity of the former could be substituted for, say, 10 lbs. of the latter.

The oats contain 9 per cent. of digestible protein and 57 per cent. digestible non-nitrogenous nutrients (reckoned as starch), *i.e.* 0·9 lb. of the former and 5·7 lbs. of the latter in 10 lbs. of the food. The beans contain 19 per cent. of digestible protein and 51 per cent. of "starch"; so 4·7 lbs. of beans would contain the required amount of protein, but only

2·4 lbs. of "starch"—less than half what is required. On the other hand, 11·2 lbs. of beans contain the required amount of "starch" and 2·1 lbs. of digestible protein—more than double the required quantity of the latter.

It comes to this, that since the N-ratio of the oats is 6·3 to 1, and that of the beans is 2·7 to 1, the difference in composition cannot be reconciled by any means. If two foods have the same N-ratio, they can replace each other in equivalent quantities, but otherwise one cannot be substituted for the other without altering the amounts either of nitrogenous or of non-nitrogenous nutrients in the ration. That is, in brief, the whole problem in compounding rations; the N-ratios of the foods differ from each other, and, as a rule, also from the standards set up. It is, of course, a very rare case that an animal is fed entirely on a single food. More commonly the rations comprise two or three or more different kinds of feeding stuff, and the problem is to combine them in such proportions as to yield the specified amounts of nitrogenous and non-nitrogenous nutrients.

Two Foods.—Any two foods can be combined in one proportion, and in one proportion only,[1] to give any specified amounts of protein and "starch," provided the N-ratio of one of them is closer, and that of the other is wider, than the N-ratio of the specified dietary. That proportion can often be determined more or less accurately by a shrewd guess. Such, probably, is the method adopted by most farmers in practice, and such is the method commonly described in text-books intended for their use.

Example.—To find what quantities of linseed cake and rice meal should be used in order to produce a specified ration from the following data:—

	Digestible protein. Per cent.	"Starch." Per cent.	N-ratio.
Linseed cake	25	56	2·24 to 1
Rice meal	6	65	10·83 ,, 1
Dietary	10	60	6·00 ,, 1

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[1] In the special case of two foods, both of which have the same N-ratio as the specified dietary, they can be combined in any proportion whatever.

Method.—Try equal quantities of the two foods.

	Protein. Lbs.	"Starch." Lbs.	N-ratio.
100 lbs. Cake contain	25	56	
100 ,, Rice ,, ...	6	65	
200 ,, Mixture ,, ...	31	121	4 to 1

The quantity of protein is about three times, and the starch is twice, as much as is required. It is necessary, therefore, to take smaller quantities of both foods and a smaller proportion of cake. Try half the quantity of rice and a fourth of the cake.

	Protein. Lbs.	"Starch." Lbs.	N-ratio.
25 lbs. Cake contain . . .	6·25	14·0	
50 ,, Rice ,, . . .	3·00	32·5	
75 ,, Mixture ,, . . .	9·25	46·5	5 to 1

This contains too little protein and much too little "starch," so more rice must be used.

	Protein. Lbs.	"Starch." Lbs.	N-ratio.
25 lbs. Cake contain . . .	6·25	14·00	
75 ,, Rice ,, . . .	4·50	48·75	
100 ,, Mixture ,, . . .	10·75	62·75	5·9 to 1

The proportions are now nearly right, but the quantities are too large. By further guessing and testing the result, it can be shown that 22½ lbs. of cake and 73 lbs. of rice meal together contain very nearly the required quantities of protein and starch. This method is, however, clumsy, tiresome, unscientific, and unsatisfactory in all respects. The exact result can be found much more quickly and more easily in other ways.

Arithmetical Method.—Consider, first, the simple case of a dietary having an N-ratio of 6 to 1, and two foods (*a*) and (*b*) having N-ratios of 5 to 1 and 7 to 1 respectively. It is evident that the excess in (*a*) is exactly equal to the deficiency in (*b*). If the N-ratio in (*a*) were 4 to 1, the excess would be twice as great as the deficiency in (*b*), and it would be necessary to take two parts of (*b*) to one of (*a*). The required proportions can, therefore, be found by comparing the N-ratios of the foods with that of the dietary.

Now take the actual case of linseed cake and rice meal as before. The differences between the ratios are—

$$6 - 2{\cdot}24 = 3{\cdot}76 \quad \text{and} \quad 6 - 10{:}83 = -4{\cdot}83$$

If the foods contained the same percentages of protein they should be taken in that proportion, *i.e.* 3·76 parts of rice meal to 4·83 of cake, or 0·773 of the former to 1 of the latter. As, however, the cake contains 4·16 times as much protein as the rice [0·773 × 4·16 =] 3·24 parts of rice should be taken to 1 of cake. The whole calculation may be briefly rendered thus—

$$\frac{(6 - 2{\cdot}24) \times 25}{(10{\cdot}83 - 6) \times 6} = \frac{3{\cdot}76 \times 25}{4{\cdot}83 \times 6} = \frac{3{\cdot}24}{1}$$

	Protein. Lb.	"Starch." Lbs.
3·24 lbs. Rice contain	0·194	2·106
1·00 ,, Cake ,, ...	0·250	0·560
4·24 ,, Mixture contain	0·444	2·666

$$\frac{4{\cdot}24 \times 10}{0{\cdot}444} \times \frac{3{\cdot}24}{4{\cdot}24} = 73 \text{ lbs. rice}$$

$$\frac{4{\cdot}24 \times 10}{0{\cdot}444} \times \frac{1}{4{\cdot}24} = 22{\cdot}5 \text{ lbs. cake}$$

The reasoning in the above calculation is rather involved, but it may be illustrated by simple graphic methods.

Graphic Solutions.—If the percentages of protein and "starch" be plotted on the axes *ox* and *oy* (Fig. 15), a line ON can be drawn to represent the ratio of the dietary (6 to 1), and two others, OL and OR representing the N-ratios of the cake (2·24 to 1) and of the rice (10·83 to 1) respectively. If, now, a straight line AE be drawn to cut these ratio lines, the two portions, AD and DE, will represent the difference between the N-ratios of the foods and that of the dietary. Through D draw CG at right angles to AE, and cut off DC equal to the percentage of protein in the cake, and DG equal to the percentage in the rice; the areas of the completed rectangles, ABCD and DEFG, represent the relative proportions in which the two foods should be used to produce the N-ratio (6 to 1) of the dietary. If the figure is drawn on squared paper, the areas of the rectangles are easily computed.

This method takes time, and it does not give a very accurate result, but it serves to illustrate the reasoning involved in the arithmetical method. It can, however, be rendered, at once, simpler and more accurate, as is shown in the following paragraph.

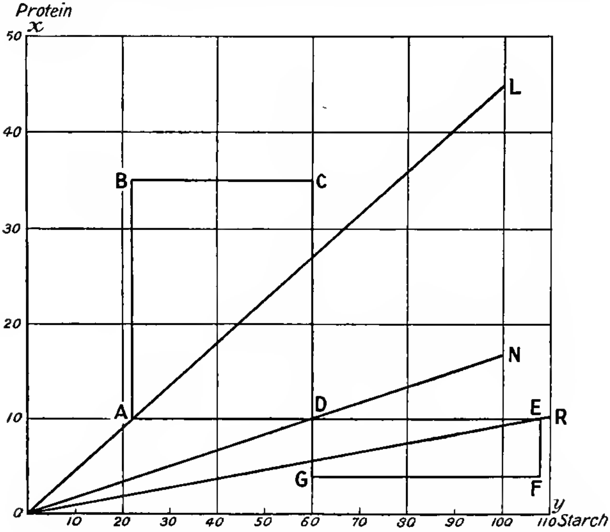

FIG. 15

If the points A and E, on the lines OL and OR, be selected according to the percentages of nutrients in the foods, the straight line joining these two points will be divided at D, in the proportions in which the foods must be taken to give the N-ratio represented by the line ON—that of the dietary.

In the diagram (Fig. 16) the points A and E occupy the same relative positions as the linseed cake and the rice meal in the chart (p. 230); and the straight line joining these two points intersects the line ON at D. If the two parts AD and

DE be now measured it will be found that they stand in the ratio of 3·24 to 1, *i.e.* in the proportions in which the foods must be used to give an N-ratio of 6 to 1.

N.B.—The proportions must be taken inversely—3·24 parts of rice meal to 1 of linseed cake.

This is one of the quickest and easiest methods of finding the relative proportions in which two foods must be combined to give any specified N-ratio. It can be readily applied even by those who do not understand the principles on which it is based. All that is necessary is to mark the positions of the two foods on a piece of squared paper, join the two points, and then draw the ratio line of the specified dietary. If these two lines intersect, the lengths of the parts AD and DE can be measured off with a pair of compasses with sufficient accuracy for practical purposes. If the two lines do not intersect, the specified N-ratio cannot be produced by any combination of the two foods in question.

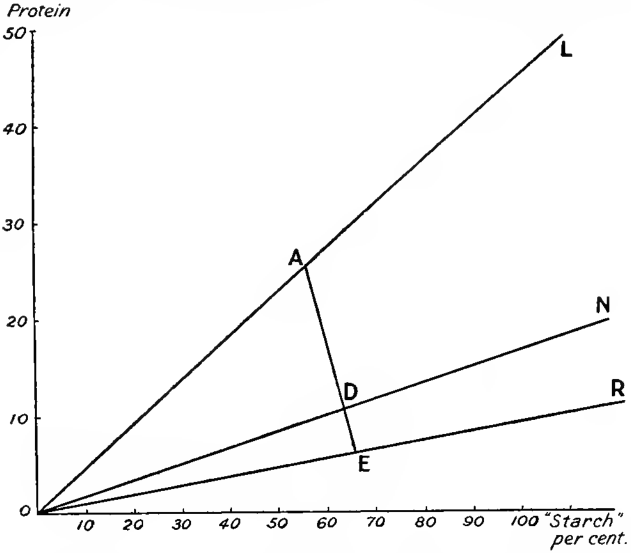

FIG. 16.

Cor. 1. The point D is the position, on the chart, of a mixture of the two foods in the proportions represented by the parts AD and DE of the line AE.

Cor. 2. If the positions of any number of foods be plotted on a chart in the manner described, and any two of them be joined by a straight line, every point on that line represents the position of a mixture of these two foods in the same proportions as the two parts into which the line is divided at the given point.

Cor. 3. If the positions of any two foods both lie on the same side of the N-ratio line of the dietary—either above or below it—the line joining these two points will not intersect the latter. The specified N-ratio cannot, therefore, be obtained from these two foods.

Cor. 4. If the position of any food on the chart lie near the ratio line of the dietary, that food will have nearly the N-ratio required, and only a small proportion of some other food on the opposite side of the line will be required to balance it.

Cor. 5. If the position of any food on the chart lie far away from the N-ratio line of the dietary, a large proportion of some other food on the opposite side of the ratio line will be required to balance it.

These graphic methods, it will be seen, do not give the actual quantities, but relative proportions only; but when these have been found the actual quantities are easily discovered as shown (p. 235). If the relative proportions are not required, the actual quantities can be calculated directly, as follows:—

$$\frac{(6 - 2{\cdot}24) \times 10 \times 100}{(10{\cdot}83 - 2{\cdot}24) \times 6} = 73; \quad \frac{(10{\cdot}83 - 6) \times 10 \times 100}{(10{\cdot}83 - 2{\cdot}24) \times 25} = 22{\cdot}5$$

Algebraic Methods.—Those who have a knowledge of elementary mathematics will have perceived that problems of this kind can be more readily solved by the method of simultaneous equations. It is much simpler than the purely arithmetical process, and the reasons for the successive steps are more apparent.

Take the same example as before: what quantities of linseed cake and rice meal are required to furnish 10 lbs. of digestible protein and 60 lbs. of "starch"?

The quantities are to be such that the protein in the cake plus that in the rice will together amount to 10 lbs.; and the "starch" in the cake plus that in the rice will together amount to 60 lbs. If the unknown quantities of cake and rice be respectively designated by the symbols x and y the proposition may be stated in the form of two (simultaneous) equations, thus—

$$0{\cdot}25x + 0{\cdot}06y = 10; \quad 0{\cdot}56x + 0{\cdot}65y = 60$$

By division—

$$x + 0{\cdot}24y = 40{\cdot}0; \quad x + 1{\cdot}16y = 107{\cdot}14$$

By subtraction—

$$0{\cdot}92y = 67{\cdot}14$$
$$y = 72{\cdot}98$$

By substitution—

$$x = 40 - (72{\cdot}98 \times 0{\cdot}24)$$
$$x = 22{\cdot}48$$

A similar method may be employed to determine the relative proportions instead of the actual quantities in which two foods should be combined to produce a given N-ratio (say 6 to 1). The proposition is stated exactly as before, but in this case the object is to eliminate the numerical terms, and obtain x and y in terms of each other.

$$25x + 6y = 1; \quad 56x + 65y = 6$$

By division—

$$25x + 6y = 1; \quad 9{\cdot}33x + 10{\cdot}83y = 1$$

By subtraction—

$$15{\cdot}67x - 4{\cdot}83y = 0$$
$$15{\cdot}67x = 4{\cdot}83y$$
$$3{\cdot}24x = y$$

The proportions are 3·24 parts of rice meal to 1 of cake.

Simplified Arithmetical Method.—If, in the last example, the symbols x and y be left out altogether, and we consider merely the arithmetical operations involved, it will be seen that they come to this, which may be regarded as the rule:

Divide the percentages of "starch" in each food by the ratio number (in this case 6) of the dietary; put the quotients to the percentages of protein, each to each, and subtract the less from the greater in each case.

The following example will make this clear:—

	Linseed cake.	Rice meal.
Percentage of "starch"	56·00	65·00
Divided by 6	9·33	10·85
Percentage of protein	25·00	6·00
By subtraction	15·67	4·83
By division	3·24	1·00

As before, the quantities are to be taken inversely, *i.e.* 3·24 parts of meal to 1 of cake.

Substitution of Foods.—It was shown at the beginning of this chapter that one food cannot replace another without altering the amount of one of the nutrients in the ration, unless they have the same N-ratio. Such a condition is found in the case of malt dust and cocoanut cake, and $1\frac{1}{2}$ lbs. of the former is equivalent to 1 lb. of the latter.

One food, however, can always be replaced by two others, provided the N-ratio of one of them is closer, and that of the other is wider than the N-ratio of the food for which they are to be substituted.

Suppose, for example, that the rations of an animal include a quantity of pollards, and that it is desired to substitute rape cake and locust beans for the same, it is easy to calculate the quantities required. Let the data be as follows:—

	Protein.	"Starch."	N-ratio.
Pollards	12·0	63	5·25 to 1
Rape cake	22·0	44	2·00 ,, 1
Locust beans	3·5	73	20·85 ,, 1

The problem is to calculate what quantities of rape cake and locust beans together contain the same amounts of protein and "starch," as, say, 100 lbs. of pollards, *i.e.* 12 lbs. of protein, and 63 lbs. of starch. It can obviously be worked out by the methods described above.

$$0{\cdot}22x + 0{\cdot}035y = 12\,;\ 0{\cdot}44x + 0{\cdot}73y = 63$$

$$x = 45{\cdot}14 \text{ and } y = 59{\cdot}1$$

or

$$22x + 3{\cdot}5y = 1\,;\ 44x + 73y = 5{\cdot}25$$

$$1{\cdot}31x = y$$

That is to say, 45·14 lbs. of rape cake and 59·1 lbs. of locust beans are together equal to 100 lbs. of pollards, *i.e.* contain 12 lbs. of protein and 63 lbs. of "starch." The second equation shows that whatever quantity is used the foods must be taken in the proportion of 1·31 lbs. of locust beans to 1 of cake.

Three Foods.—It was shown above that two foods can be combined in one proportion only, to satisfy any given conditions. If there be more than two foods they can be combined in an indefinite number of different[1] proportions to satisfy any given conditions; but there are limits to the amount of each food that can be used along with the others.

When three foods are used, the N-ratio of one of them must be closer and that of another wider than the N-ratio of the dietary. The N-ratio of the third may be either closer or wider. Thus it may happen that the N-ratios of two of the foods are closer and that of the third is wider than the N-ratio of the dietary, or *vice versâ.* The foods may be grouped accordingly, and there will always be two foods in one group and one in the other.

Let the three foods be *a*, *b*, and *c*, of which the N-ratios are 4 to 1, 5 to 1 and 7 to 1 respectively; and let the N-ratio of the dietary be 6 to 1. Then *a* and *b* would be placed in one group, because the N-ratio of both is closer than that of the dietary, and *c* would be placed by itself in the other group, because its N-ratio is wider. Now, the quantities of the foods are to be so adjusted that the protein in one group plus the protein in the other is to be equal to 1, and the "starch" in the first group plus the "starch" in the second is to be equal to 6. It will be seen that the N-ratio of the dietary could be obtained by a combination of *a* and *c*, or of *b* and *c*, but not by any combination of *a* and *b*, because the N-ratio of both is wider than that of the dietary. In other words, the minimum quantity of either of these foods is zero; and the maximum quantity is that which will give the specified N-ratio in combination with *c* alone. The minimum quantity

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[1] This is only another way of saying that three numbers cannot be determined by two equations.

of *c* is that which gives the specified N-ratio in combination with *b* alone (because the N-ratio of *b* is nearer to that of the dietary than that of *a*), and the maximum quantity of *c* is that which gives the specified N-ratio in combination with *a* alone.

The meaning of these facts will, perhaps, be clearer if we consider an actual case. Let the data be as follows:—

Foods.	Protein. Per cent.	"Starch." Per cent.	N-ratio.
Linseed cake	25	56	2·24 to 1
Rice meal	6	65	10·83 ,, 1
Oat straw	1	40	40·00 ,, 1
Dietary	10	60	6·00 ,, 1

In this case, the N-ratio of the cake is closer than that of the dietary, and those of the other two—the rice meal and the oat straw—are both wider. The specified N-ratio (6 to 1) can, therefore, be obtained from the cake and meal alone, or from the cake and straw alone, but not from the meal and straw. The minimum quantity of either meal or straw is therefore zero, and the maximum quantities are those of either food which would give the specified N-ratio with cake alone. The minimum quantity of cake is that which gives the specified ratio in combination with rice meal alone, and the maximum quantity is that which gives the specified ratio in combination with straw alone.

These quantities are easily calculated as before. Let the cake, meal, and straw be designated by the symbols x, y, and z, then we have—

$$25x + 6y = 10\,;\ \ 56x + 65y = 60$$
$$x = 22{\cdot}48\,;\ y = 72{\cdot}98\ \text{(see p. 239)}$$

$$25\,x + 1z = 10\,;\ \ 56x + 40z = 60$$
$$x = 36{\cdot}02\,;\ z = 99{\cdot}5$$

The straw may be used in any quantity from 0 up to 99·5 lbs., and the meal in any quantity from 0 up to 72·98 lbs., and the quantity of cake required to complete the dietary will vary accordingly from 22·48 lbs. when combined with meal alone, up to 36·02 lbs. when combined with straw alone; but it can never fall to 0. It is because the straw and meal can be used in any relative proportions, within the limits mentioned, that an indefinite number of combinations can be arranged to give the specified N-ratio.

If the quantity of any one of the three foods be fixed, arbitrarily or otherwise, those of the other two are thereby determined and can be calculated as before. The fixing of the quantity of one of the foods gives a third equation. Example: to find what quantities of cake and meal must be combined with 50 lbs. of straw to give a dietary of 10 lbs. of protein and 60 lbs. of "starch." Let the other data be as before (p. 242). The proposition may be stated thus—

$$0{\cdot}25x + 0{\cdot}06y + 0{\cdot}01z = 10;\ 0{\cdot}56x + 0{\cdot}65y + 0{\cdot}4z = 60;\ z = 50$$

$$0{\cdot}25x + 0{\cdot}06y = 10 - (0{\cdot}01 \times 50);\ 0{\cdot}56x + 0{\cdot}65y = 60 - (0{\cdot}4 \times 50)$$

$$0{\cdot}25x + 0{\cdot}06y = 9{\cdot}5;\ 0{\cdot}56x + 0{\cdot}65y = 40$$

$$x = 29{\cdot}28;\ y = 36{\cdot}33;\ z = 50$$

If 50 lbs. of straw is used, it must be combined with 29·8 lbs. of cake and 34·16 lbs. of meal to give 10 lbs. of protein and 60 lbs. of starch.

Again, suppose that 24 lbs. of cake had been specified instead of 50 lbs. of straw, the calculation would have been as follows:—

$$0{\cdot}25x + 0{\cdot}06y + 0{\cdot}01z = 10;\ 0{\cdot}56x + 0{\cdot}65y + 0{\cdot}4z = 60$$

$$x = 24$$

$$0{\cdot}06y + 0{\cdot}01z = 4 \qquad 0{\cdot}65y + 0{\cdot}4z = 46{\cdot}56$$

$$y = 64{\cdot}83;\ z = 11{\cdot}07;\ x = 24$$

Of the indefinite number of possible combinations of these three foods which can be arranged to give the specified dietary, four have been calculated above, and the results are given, for comparison, in tabular form below.

Combination.	I.	II.	III.	IV.
Straw	—	11·0	50·0	99·5
Meal	73·0	64·8	36·3	—
Cake	22·5	24·0	29·3	36·0

It will be seen that as the quantity of straw increases from 0 to maximum, the quantity of meal diminishes from maximum to 0, and that the quantity of cake to be used with each combination of the other two varies from minimum (22·5) to maximum (36).

The case of three foods may also be investigated by graphic methods. They are, perhaps, too complicated to be of much practical use as a means of solution, but as they help to illuminate the subject they may be briefly described.

In the diagram (Fig. 17) the points A, E, and E′ occupy the same relative positions as the cake, meal, and straw in the chart (p. 230). As before, the two parts, AD and DE, of the line AE represent the proportions in which the meal and cake must be taken when no straw is used. Similarly, the two parts, AD′ and D′E′ represent the proportions in which the straw and cake must be taken when no meal is used. Now, let the line E′E be divided at any point *e*; this point represents the

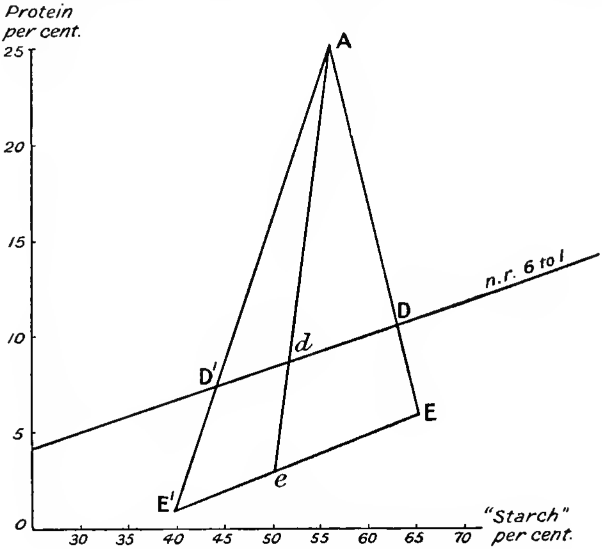

FIG. 17.

position on the chart of a mixture of meal and straw in the proportions represented by the two parts, $E'e$ and eE (Cor. 2, p. 228). Join Ae, cutting the ratio line at the point d; then de represents the quantity of the cake, and Ad the quantity of the mixture. But the mixture consists of $E'e$ and eE; therefore $\frac{Ad \times Ee}{E'E}$ represents the quantity of straw, and $\frac{Ad \times eE'}{E'E}$ represents the quantity of meal required to produce the (ratio 6 to 1) represented by the line $D'D$.

The quantities so obtained are, of course, not actual but relative, *i.e.* they represent the proportions in which the foods must be taken. The point e may be fixed at any point on the line EE', because the cake and straw may be taken in any proportion within the limits fixed by the points E and E'.

More than Three Foods.—It is unnecessary to discuss at length cases of rations composed of more than three foods. They are all investigated in a similar manner, and they are all subject to the condition that the N-ratio of one of the foods must be closer, and that of another wider than the specified N-ratio of the dietary. It is a matter of indifference whether the N-ratios of the remaining foods are closer or wider, but the foods must be grouped accordingly. The quantities of the foods are to be adjusted so that the protein in one group plus the protein in the other is equal to the amount specified, and the "starch" in one plus the "starch" in the other is also equal to the amount specified.

When four foods are used, there may be two foods in each group; or there may be three foods in one group and one in the other. In any case, there will always be more than one food in one of the groups; and, since these can be taken, within certain limits, in any proportion, an indefinite number of combinations can be arranged to satisfy the conditions. If the quantities of two of the foods out of four are fixed, the quantities of the other two are thereby determined and can be calculated as before. If the quantity of one food out of four is fixed, the maximum and minimum quantities of the other three that can be used along with it can be calculated.

It usually happens that the quantity of one or more of the foods is or can be fixed. Considerations of expense, the health of the animals, and so on, are the deciding factors. It is, therefore, as a rule, merely a matter of calculation to discover in what proportions the foods should be combined to satisfy any given conditions.

CHAPTER XV

SUCCULENT AND WATERY FOODS

General Characteristics.—The distinction between dry and watery foods is at once plain and important. The former contain only hygroscopic moisture, which rarely exceeds 20 per cent. of the whole, and in many cases it is less than half that amount. The average is, perhaps, from 10 to 12 per cent. The latter, the watery foods, consist of fresh vegetables which usually contain over 75 per cent., and not infrequently as much as 90 per cent. of water. The percentage of nutrients in such watery foods is, therefore, relatively small, and large quantities of the foods are required for nutrition of animals.

Thus, apart from any differences in composition or digestibility due to drying, 1 lb. of hay would be equal to about 4¼ lbs. of the fresh grass from which it was made. An animal which required 20 lbs. of such hay for maintenance would need from 80 to 90 lbs. of grass for the same purpose, and it would need an additional 50 lbs. or so in addition for milk production or fattening. This total quantity of grass—if the animals were able to consume so much—would contain nearly 11 gallons of water. This is more than they require or would consume if fed on dry food under ordinary conditions.

The excess of water is, of course, rapidly excreted; but as it is first raised to the temperature of the animal's body, there is a certain loss of energy (p. 124). There is some reason to believe that the increased volume of urine carries with it a larger amount of nitrogen, but this has not been definitely proved. It has also been suggested that large amounts of watery foods must tend to depress the digestibility of the nutrients as a result of the excessive dilution of the juices.

Practical farmers, however, attach very little importance to these considerations. The majority seem to believe that watery foods even in large amounts are neither uneconomical nor objectionable on physiological grounds. There are, of course, other reasons, previously mentioned, why milk cows and fattening cattle should receive a certain amount of dry (concentrated) food, but there seems to be no valid reason why store animals should not be fed entirely upon watery foods provided the same contain a sufficient amount of protein for their maintenance.

The succulent and watery foods generally have a certain laxative effect, and they are relished by the animals. The large quantities which are required are very heavy to handle. It would not be profitable to transport them to any considerable distance. They are, however, almost invariably home grown, and to a large extent they are consumed in the field.

Roots.—In England the ordinary root crops are cultivated as biennials. The whole of the first season is devoted to vegetation, and the large amount of material formed is stored up in the bulbous roots against the time of seed formation. This material consists mainly of carbohydrates, together with a certain amount of nitrogenous substance and a very small amount of fat; it is, therefore, suitable for nutrition of animals. This material is formed in the leaves and subsequently transferred to the roots. When the leaves are completely exhausted they die and drop off. Those which remain green until the crop is "pulled" are probably of more value as a source of humus in the soil than as food for animals. They are of fibrous structure, and any nutrients they may still contain are probably difficultly digestible. As there is practically no stem, it is only the bulbous root that is of value as a cattle food.

The roots consist of a strong outer shell or rind of lignified fibre in which the nutritive substances mentioned above are enclosed. They usually contain in the neighbourhood of

90 per cent. of water, and consequently have a specific gravity of nearly one. It is said that "white turnips just float and swedes just sink," but many individual specimens may be found in which this rule is reversed.

It was at one time supposed that the specific gravity of the roots would afford a reliable indication of their nutritive value, but it has been definitely established that this is not even approximately true. The specific gravity of any individual root apparently depends mainly upon the size and number of the air cells it contains. Those which contain the most, *i.e.* those which have the lowest specific gravity, will, under similar conditions probably germinate most readily, and will, therefore, be the least suitable for "keeping."

The carbohydrates consist chiefly of pectocelluloses and sugars. In sugar beet the latter compound is almost entirely of the cane sugar type; in others, *e.g.* swedes, mangels, etc., it consists wholly or partially of glucose. The percentage of sugar is smallest in the stalks, and increases from above downwards. Samples of roots should, therefore, always be radial sections through the centre. The whole of the sugar occurs in solution in the juice, and the larger part of it may be extracted by pressure.

The percentage of fat is so small as to be practically negligible. The total nitrogenous matter may amount to from 1 to 1½ per cent., but it is practically all non-proteid in character. The nutrients of the roots are, therefore, almost entirely carbohydrate.

The sugars, being in solution, are of course completely digestible. The pectocellulose, or pulp, is extremely soft and easily hydrolysed. The whole of the non-cellulose portion (p. 29), and probably also the larger part of the cellulose, is digestible. In fact, the only indigestible portion of the root appears to be the lignified fibre of the outer rind, and this part is often not eaten by the animals. On reference to the table of composition (p. 213), it will be seen that apart from the amount of water they contain—and this is too variable to be truly characteristic—turnips, swedes, mangels, and carrots do not differ much in chemical composition as determined by ordinary analyses. The first two are, however, less suitable for milk cows, as they have a tendency to impart a peculiarly disagreeable flavour to the milk.

Sugar beet are not largely used for cattle feeding. When the crop is grown, the roots are generally sold to the sugar factories. They may, however, be fed to the stock along with other foods. They are relished by the cattle, but, owing to the large amount of sugar they contain, they have a very sweet taste, and are apt to cloy the palate if excessive quantities are given. The residues which remain after extraction of the sugar (beet slices) may be used either in the fresh or dried condition. They consist mainly of the pectocelluloses, but contain also a certain amount of sugar. The percentage of the latter substance is, however, very variable. It depends largely upon the method of extraction used. When the composition of sugar beet is compared with that of swedes and mangels, it is seen that 1 ton of the former is equal to from 2 to 2½ tons of the latter for feeding purposes.

The pecuniary values assigned to the roots in the tables (p. 215) are the estimated "consuming values" or cost of production. At those rates it was shown that they are very economical both for maintenance and for special purposes (fattening, etc.). The cost of transport of such watery materials is practically prohibitive, and they are rarely sold in towns. When they are sold, the market prices are often nearly double those assumed in the tables, and under these circumstances the roots compare unfavourably with many other foods.

Potatoes are often classified with the roots. The cultivation required is similar, and they are often grown in the same field. The whole are referred to as green crop. The bulb or tuber of the potato plant, however, is not botanically homologous with the roots of turnips, etc. It is an underground stem which is specialised for a similar purpose, *i.e.* for the accumulation of nutrients against the time of seed formation.

The proportion of water in the tuber is only about 75 per cent., and the carbohydrate consists mainly of starch. In other respects they closely resemble the roots. The proportion of nitrogenous matter is small, and only a fraction of it is true protein. Fats are absent or present only in very small amount. Potatoes are, therefore, almost entirely a carbohydrate food. The coefficient of digestibility is high, and the nutritive value of the whole is very similar to that of sugar beet.

Forage Crops.—Under this head are included all those succulent green fodders of which the edible part consists of the stem and leaf of the plant. Nearly all of them belong to one or other of the three botanical orders, cruciferæ, leguminosæ, or gramineæ. They are annuals, and the nutrient substances, accumulated in the stems and leaves by the processes of vegetation, are to a large extent exhausted when seed formation occurs. In no case, therefore, should the plants be allowed to develop beyond the stage of flower. As they approach this stage the percentage of fibre rapidly increases and the percentage of water ash and nitrogenous matter is correspondingly diminished.

These crops vary in composition, perhaps, more widely than those of any other class. Apart from the differences in the several kinds of plant, the variation may be referred almost entirely to the degree of maturity. The leaves contain more nitrogenous matter than the stems, and the proportion of stem to leaf increases as the age of the plants advances. The maturity is also largely affected by external conditions—soil, manuring, climate and season.

As compared with the roots, the forage crops are, on the whole, less watery. The percentage of nitrogenous matter is greater, and a larger proportion of it is true protein; the amount of amides is, however, considerable. The forage crops are more fibrous than the roots, and the coefficients of digestibility are lower.

The order cruciferæ is represented chiefly by cabbage, kohl-rabi, rape, and mustard. The first two are largely used for milk cows. The others are frequently grown as catch crops for which purpose they are peculiarly suitable. They are then generally eaten off by sheep and the residue is turned down. A certain amount of autumn "keep" is thus provided for the animals, and the land is effectively manured with a minimum of labour.

The leguminous forage crops include clovers, vetches, lucerne, lupines, sainfoin, etc. They are generally somewhat less watery and more highly nitrogenous than the crucifers. Up to the time of flowering, the coefficients of digestibility are high, but after that stage the fibre lignifies very rapidly and the ratio of dynamic to thermic value is greatly diminished. Lupines which grow well on poor sandy soils are sometimes fed to sheep, but they are cultivated more largely for the purpose of green manuring than for feeding. In the mature condition they have an extremely bitter taste which is disagreeable to animals. This taste has been ascribed to the presence of alkaloids of a poisonous character. More recently the poisonous effects, which are commonly, but not always, noticeable, have been attributed to the presence of parasitic fungi, and it is said that they can be destroyed by subjecting the dried material to prolonged steaming. Other leguminous crops are largely used for cows, and in the young condition are said to promote the flow of milk.

The grasses are rarely cut for consumption in the green state, but they form, quantitatively, by far the most important ingredient of the herbage of pastures. No inferences drawn from the properties of meadow grasses can be applied even to the same varieties in pastures. The conditions are very different. The herbage in pastures is kept down by the grazing animals, and the whole of the produce is, therefore, consumed in a very immature state. This herbage is much softer, richer, less fibrous and altogether more valuable, weight for weight, than the produce of the same meadow when cut for hay. Under the circumstances of pasture, the differences which are more or less characteristic of the several varieties do not develop; the chemical composition and digestibility of all are practically alike.

Pastures differ, however, very greatly in quality, and the fact is attributable mainly to two causes. Certain varieties of grass, *e.g.* cock's-foot, timothy, rye grass, fescues, grow more rapidly, and so tend to produce a greater bulk of produce than others under similar conditions. Also the herbage of pastures does not consist entirely of grasses, but includes other plants in varying proportions. Of the latter, clovers are by general consent the most esteemed. Plantains, sedges, mosses, etc., are deservedly regarded with disfavour.

The composition of the herbage of an old pasture depends mainly upon accidental conditions such as soil, manuring, climate, season, grazing, etc., and only to a small extent on the seed originally sown.

Barley, oats, rye, maize, sorghum, etc., are sometimes cut green for use as forage. This practice, however, can only be recommended under exceptional circumstances. The total bulk of crop, its chemical composition and digestibility all depend largely on the stage of growth. All things considered, the most advantageous time at which to cut these crops is just before flowering. In this condition the material resembles a rather stalky grass. The climate in most parts of England is generally too cold for the growth of maize even as a forage crop, and a more profitable yield is obtained with other plants.

Preservation of Succulent Fodders.—No means have yet been discovered by which succulent vegetable matter can be preserved unchanged for any length of time. Roots and tubers are generally stored in dry barns or, preferably, in pits dug in the ground, lined with straw, and so arranged as to prevent the access of moisture. Under either condition they do not remain entirely quiescent, but gradually undergo chemical changes due to incipient germination. These changes are of a fermentative character, and are caused by enzymes occurring naturally in the organism. The general tendency of such changes, it has been shown (p. 85), is to break down complex molecules into simpler ones. Proteins are largely split up into amino-acids; but as practically the whole of the nitrogenous matter is present in that condition in the original roots and tubers probably this change does not occurr to any considerable extent. The soluble carbohydrates are affected in greater degree. Starches are resolved into sugars, and the latter suffer various further changes. Alcohol, lactic acid and a large amount of carbon dioxide are produced. Pecto-celluloses are probably also resolved first into hydrated cellulose and mucilages, and then into sugars which suffer the same fate as those formed from starch. The lignified celluloses are not known to undergo any change. Any fats that may be present are probably also hydrolysed.

The extent to which such changes may occur depends chiefly upon two factors, viz. the temperature and the access of air. During the colder months of the year, the changes proceed very slowly, but as the temperature rises with the advance of spring, they are accelerated and a considerable loss of nutrients results. When roots are sliced or pulped a large surface is exposed to the air, and the changes proceed very rapidly; if piled in heaps, so as to conserve the heat produced, the temperature rises, and if due care is not taken it may become high enough to char the sugars. This method of preparing the food is often resorted to because it is considered that the fermentation—if not carried too far—renders the roots more palatable to the animals. However that may be, it involves a certain loss of carbohydrates, and it is undoubtedly laborious. Two inferences may be drawn from these facts, namely: (1) Care should be taken not to bruise or cut the roots before storing. Otherwise, the rapid fermentation which sets in owing to the access of air may spread to the whole heap and spoil it. (2) Storing in pits is the more efficacious method, as the air is more thoroughly excluded and a more even, low temperature is maintained.

Grass, clover, vetches and other succulent herbs when collected together undergo changes similar to those described above, but even more rapidly, and soon become unfit for use as food. If, however, the heaps are very highly packed, so as to exclude the air as far as possible, fermentation is not entirely arrested, but it takes place much more slowly, and the product forms a palatable fodder to which the name of ensilage—or more shortly "silage"—is generally applied. If made in a heap or "stack," as suggested above, the exterior portion, which is, of course, in contact with the air, becomes charred and unfit for use. In order to prevent this waste of fodder, the material is sometimes placed in a pit—called a silo—dug in the ground; but as these silos must be lined with cement or other material impervious to moisture, the expense is greater than that involved in the waste of fodder when the silage is make in a stack. Silos are also sometimes built above ground. These are much more convenient but more expensive.

Whichever method is adopted, fermentation sets in very radidly, the temperature rises, large amounts of carbon dioxide are evolved and great loss of nutrients ensues. This loss of course falls most heavily upon the more readily soluble, *i.e.* the most digestible constituents, and it may amount to from about a quarter to nearly half of the total organic matter. Further, much of the protein which is not entirely lost is greatly depreciated in value by being split up into amino-acid bodies. As against this, however, may be set the fact that some of the lignified, or partially lignified celluloses are also acted upon and probably rendered more readily digestible.

The loss of nutrients in making ensilage can be reduced to a minimum by tightly packing the material as the stack is built up, and then applying great pressure on the top. Under these conditions the fermentation which takes places is largely of the butyric type, and the product has a disagreeable rancid taste and an extremely offensive odour. It is called "sour silage" in contradistinction to the so-called "sweet silage," which is produced when the stuff is more loosely packed and pressure is not applied until the temperature has risen to about 70° C.[1] This inhibits the action of the butyric ferments, and the fermentation which occurs is mainly of the alcoholic and lactic types. The product has a not unpleasant "winey" taste and smell, and is much more palatable. This method is, therefore to be preferred, but it involves a much greater waste of material. A semi-sour or semi-sweet silage is produced at intermediate temperatures, *i.e.* about 55° to 60° C., and the loss by fermentation is correspondingly reduced. Sour silage has a highly laxative effect and is apt to produce scouring.

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[1] At higher temperatures the substance chars.

The excess of acid can be neutralised by sprinkling precipitated chalk over the fodder.

When the expense of a built silo or the alternative loss due to charring at the outside of a stack is added to the losses due to fermentation, it is obvious that silage making is not a profitable method of preserving fodder; it is now rarely practised in this country. On the other hand, it is not so laborious (expensive) as making hay, and the risk of loss by bad weather is practically eliminated. These considerations are of so much importance that silage-making is probably the best method of preserving succulent fodders which, for any reason, cannot be gathered until late autumn or in very wet summers. It has also been urged that turnip tops, potato haulm, maize stalks and all sorts of rubbish can be made into silage. As, however, it has been shown that silage-making does not improve, but markedly deteriorates the quality of the original materials, and the substances mentioned are of little or no value as foods to begin with, it does not appear that any great advantage is derivable in that way.

CHAPTER XVI

COARSE DRY FODDERS

Hays.—In the opinion of the vast majority of practical men, the best way of preserving herbaceous green fodders, such as grass, clovers, etc., is that which has been practised from time immemorial, namely, to make them into hay by drying in the sun. By this means, under favourable conditions, the moisture can be reduced to about 10 per cent. or even less, and the processes of fermentation are thereby almost entirely arrested. In the climate of England good hay generally contains from 12 to 15 per cent. of moisture, and when it is tightly packed in the stack, fermentation takes place very slowly. When the percentage of moisture is greater, fermentation proceeds more rapidly, and if it amounts to about 20 per cent., the product acquires some of the properties of ensilage, and is known, from its colour, as brown hay.

The nutritive value of any sample of hay depends chiefly upon three conditions, as follows: (1) the nature and quality of the herbage from which it is made; (2) the changes and losses, if any, incidental to the process of making; (3) the changes which occur after it is stacked.

Grasses, clovers, vetches, lucerne, rape, mustard, in fact almost any herbaceous plant that can be quickly dried, can be made into hay. Cabbages and other similar plants cannot well be preserved in this way. They would undergo fermentation, *i.e.* decomposition, and become unfit for use as food before all the moisture evaporated.

Grass hay is, quantitatively, the most important in this country. In fact the unqualified term "hay" always refers to this material. When any other kind is in question it is generally specified as "clover hay," "lucerne hay," etc.

A distinction of some importance is generally drawn between seed hay and meadow hay. The former is produced from seed sown the same year. It generally consists wholly, or mainly, of a single variety of grass. Rye grass is the commonest, but timothy, dog's-tail, and other varieties are sometimes grown. Owing to the conditions under which the grass is grown, seed hay consists mainly of stems with a comparatively small proportion of leaf and little or no undergrowth. It is, therefore, generally rather coarse, *i.e.* fibrous and indigestible. A richer, softer, more digestible fodder could be obtained by cutting the grass at an earlier stage of growth, but the total crop would be smaller. Seed hay is generally cut at or about the time of flowering. The differences in chemical composition of the varieties of grass commonly cultivated are so small that they cannot be regarded as characteristic. At all events, they are completely obscured by the variations due to the influence of climate, season, soil manuring, and such like accidental circumstances.

Meadow hay, the dried produce of an old lea, differs from seed hay in several important particulars. The herbage is made up of many different varieties of grass, and usually also plants belonging to the leguminosæ, compositæ, ranunculaceæ, and other orders. These various kinds of plants develop at different rates, and do not, therefore, all come to maturity at the same time. The crop is generally cut about the time when the principal grasses are at the stage of flower. These grasses then have long stems and they exhibit generally much the same properties as those of which seed hay is composed. There is, however, always a larger or smaller proportion of immature, leafy undergrowth, both from the grasses proper, and from plants of other orders. This undergrowth is richer in nitrogenous matter, less fibrous, and more digestible in character. In fact, it more nearly resembles pasture grass in composition and properties. The total amount and relative proportion of this undergrowth depend upon the kind of plants of which the herbage is made up, and the rate of development of each; and these, in turn, depend largely upon the age of the lea, climate, season, soil, and manuring. At all events, whatever the causes, it is clear that the proportion of undergrowth to flowering plants must have a considerable effect upon the composition and properties of the final product.

Various changes set in rapidly as soon as the grass is cut. The most obvious, and in many respects the most important, is the evaporation of water. The rate of evaporation depends upon the temperature, dryness of the atmosphere, wind, and the total bulk of produce. It is, therefore, very variable, but under favourable conditions it takes place very rapidly. In warm climates hay is sometimes cut in the morning and stacked the same night. In this country it is sometimes not dry enough to stack after a week's exposure.

It is well known in another connection that evaporation of water produces a bleaching, *i.e.* an oxidising action. The colour of the grass is, therefore, always much reduced. If the material is wet and dried again several times, the colour is entirely bleached. At the same time, fermentative changes occur, and a large proportion of the carbohydrates, which are present as insoluble compounds in the grass before it is cut, are rapidly resolved into soluble substances—sugars, mucilages, etc. Aromatic compounds, which give the hay a pleasant odour, are also formed. If the hay is wet by rain after these changes have taken place, much of the soluble and aromatic substances is dissolved and washed out. The soluble compounds which are thus lost are, of course, the most readily digestible nutrients. In some experiments made by the author as much as 20 per cent. of the nutrients present in the fresh grass were lost by weathering. The loss of colour and aroma are evidence of this deterioration. The growth of moulds, which cannot afterwards be got rid of, is an even more objectionable result of the weathering. These organisms, even in small quantity, are evidently very distasteful to the animals and are liable to prove injurious. The quality of hay depends more largely upon the condition in which it is "got" than upon any other single circumstance.

When the hay is stacked, fermentation continues unless the material is very dry, and changes similar to those described under ensilage (p. 254) take place. The rate of fermentation depends mainly upon the amount of water present, and the total loss of nutrients is greater or less accordingly. In parts of Cheshire, Staffordshire and elsewhere, farmers endeavour to promote this fermentation in order to produce brown hay, for which they obtain a higher price from the carters and horse dealers in the large towns. For this purpose they encourage the growth of plantains and other broad-leaved plants in their meadows. These retain moisture longer than the grasses, and so set up fermentation in the stack. Experience and fine judgment are necessary to produce the desired result. In the presence of excess of moisture, the temperature may rise so high, owing to the rapid fermentation, as to char or even set fire to the stack. The rate of fermentation can, however, be greatly diminished by applying pressure and so excluding the air.

The production of brown hay of necessity involves considerable loss of nutrients, and this loss falls at least in part on the producer. For, even if he obtains a higher price per ton, he has less weight of stuff to dispose of. Apart from the difference in price, it apparently does not affect the purchaser who buys by the ton. The brown hay has nearly the same composition, per cent., as the green or white hay, but owing to the disintegration of the protein, it is probably of inferior nutritive value. The reason why carters in towns are willing to give a higher price for brown hay is that the animals prefer it; and this may be attributed to the fact that it is practically free from moulds which are destroyed by the high temperature to which it has been exposed. So far as the author is aware, horses show no preference for brown hay rather than for good, clean, white or green stuff. For a farmer who does not sell his hay, but consumes it on the farm, the most profitable kind of hay is that which has undergone the least possible degree of fermentation. The ideal product would be the fresh grass which had undergone no change whatever except the abstraction of water. That of course is not practically attainable, but the more nearly it is approached the better. Such hay is clean, nearly free from dust when shaken, of a light green colour, and has a pleasant aroma. Hay which has been weathered and become dusty (mouldy) can be rendered palatable to the animals by steaming.

Hays made from other plants, *e.g.* clovers, lucerne, etc. exhibit certain more or less characteristic differences of composition and digestibility. They are, however, all subject to variation from the causes mentioned above.

Cereal Straws and Chaff.—Cereals are annuals. A large proportion of the nutrient material that is accumulated in the stems by the processes of vegetation is transferred to the ears at the time of seed formation, and when the crop is cut the straw is to a large extent exhausted. It consists mainly of cellulose, much of which is highly lignified. The other constituents which remain are probably less susceptible to chemical change, and, therefore, less easily digestible than those which have been withdrawn. It is obvious that the straw of plants which have produced ripe seeds cannot be of great nutritive value.

Any circumstances which interfere with the ripening of the grain, such as bad seasons, or the breaking of the straw when it is laid by rain and wind, necessarily tend to prevent the transference of the nutrient matters to the seeds, and so leave the straw of greater nutritive value. The lower sections of the straw are stouter and coarser than the upper portions. They contain more fibre and a smaller proportion of nutrient substances, and the latter are less readily digestible. When animals are given a quantity of long straw as fodder, they generally exhibit a marked preference for the upper ends, and not infrequently refuse to eat the lower portions.

It would not be advisable, however, even if it were practicable, to cut off the upper half of the straw and use that only as fodder. The grass and weeds of various kinds, which are usually present in considerable quantity, are mixed with the lower ends of the straw, and these are of greater nutritive value than the straw itself. In composition they resemble a kind of coarse meadow hay.

The chemical composition of all kinds of cereal straw is extremely variable. In fact, the variation due to the influence of accidental circumstances, such as climate, season, etc., is so great that it often obscures the characteristics of the different kinds. Of two samples of the same kind of straw, one may contain nearly twice as much nutritive matter as the other. Still, when the averages of large numbers of so-called normal samples are considered, it is generally found that oat and barley straws are more nutritive than those of wheat and rye. The straw of spring wheat, however, is generally somewhat superior to that of the autumn sown crop.

At best, cereal straws form poor feed. The ratio of dynamic to thermic energy is very low. They are only fit for use as maintenance rations, and, even for this purpose, should only form a portion of the whole. Larger quantities may be given to ruminants than to horses. When large amounts are used, the high percentage of fibre in the straw tends to depress the digestibility of the nutrients in the other foods.

In the rations prescribed by practical men, emphasis is generally laid on the fact that the straw was or was not chaffed, *i.e.* chopped into small pieces. The practical importance of this probably lies in the facility with which chopped straw may be mixed with other foods, *e.g.* pulped roots, meals, etc. Such admixture may possibly lead to more thorough mastication of the meals, etc., and so increase their digestibility, or it may act merely as an inducement to the animals to consume the straw. So far as the straw itself is concerned, it cannot make any considerable difference whether it is chopped or not, provided the same amount is actually consumed.

The term "chaff" is often applied, as indicated above, to chopped straw. Strictly, it refers only to the membranous outer husks or ears in which the grain is enclosed. These consist mainly of lignified cellulose together with a large proportion of siliceous ash. Chemical analysis reveals the presence of a certain amount of nutritive matter, but there are many objections to the use of this material for feeding purposes. The chaff of cereals includes the awns, if any, and these are liable to prove deleterious if not actually dangerous to the animals. It usually has associated with it, earthy and fungoid impurities, which are also objectionable. By absorbing the juices of the alimentary tract it tends to reduce the digestibility of other foods; it has a binding effect, and, it has been said, that owing to its mechanical condition it is liable to produce a block in the bowels of the animals.

Leguminous Straws and Husks.—Leguminous straws are subject to the same general remarks as cereal straws. They are, however, considerably richer in nitrogenous matter than the latter, and are not, as a rule, quite so fibrous. It is sometimes asserted that pea and bean straws are equal in nutritive value to good meadow hay, but that is exaggeration. Pea and bean straws are rarely equal to the inferior qualities of meadow hay. Even when they contain the same proportions of crude nutrients, the ratio of dynamic to thermic value is always lower owing to the difference in the coefficients of digestibility. They are less palatable to the animals—especially horses—than meadow hay. They are probably even less palatable than the cereal straws. This may be due to the fact that leguminous straws are even more liable to the presence of moulds and other fungi which are injurious to the health of the animals. Also they are very binding in their effects.

The husks of leguminous seeds—not the pods which go with the straw—are generally left on the seeds when these are fed to animals. They are sometimes used separately, but are of low nutritive value, and, like straws and all such fibrous materials, they tend to lower the value of other foods used along with them.

CHAPTER XVII

CONCENTRATED FOODS

UNDER the head of concentrated foods are included all those products which contain relatively small proportions of water and fibre, and which are, therefore, rich in nutrient material. It was previously shown (p. 231) that they contain more than 12 per cent. of protein, or more than 50 per cent. of non-nitrogenous matter reckoned as starch.

With few exceptions they consist of seeds, portions of seeds, or substances derived from them. For convenience of study they may be classified as seeds, cakes, meals, and industrial by-products. This classification, however, is purely arbitrary. The by-products consist chiefly of the residues obtained in brewing and distilling, and in the manufacture of starch and sugar. The more important meals are offals or by-products from the flour mills, and in a sense oil-cakes might be regarded as by-products from the oil mills.

Seeds.—All seeds consist essentially of two parts—a germ or embryo, and a store of nutrient matter to nourish it during the process of germination and until the seedling has reached a stage in which it is capable of independent existence. The embryo consists mainly of protein and fat. The nutrient matter consists partly of nitrogenous matter and partly of non-nitrogenous. The former, in properly ripened seed, is almost entirely true protein; amides are absent, or present only in very small proportion. The latter usually consists mainly either of starch, or oil, or of both in varying proportions. The ash is composed mainly of phosphates of potash, magnesium, and calcium. In the seed proper, apart from the husk, but little useless material—fibre, silica, etc.—is found, and the proportion of water is necessarily small. Such material is, therefore, eminently suitable for the nutrition of animals.

All the materials mentioned above are, as they exist in seeds, insoluble in water. They could not, therefore, be transferred to the growing points, and the seeds would be incapable of germination, if it were not that they also contain enzymes capable of resolving the substances into soluble compounds. When germination takes place, the seeds absorb large quantities of water and oxygen gas; carbon dioxide is evolved, proteins are resolved to amides and starch into sugars. Fats also are acted upon by lipolytic ferments. The products of these changes are transferred to the points of growth, and the rootlets and shootlets are formed. Seeds which have sprouted, *i.e.* germinated, are, therefore, of lower nutritive value; and when the process is complete, the seeds are entirely exhausted. The young sprouts formed from the material of the seed are, however, highly nutritious.

As seeds are enclosed in a fruit or protective covering of some kind, they are less subject to the attacks of fungoid parasites than the stems and leaves. They contain a large amount of nourishment in small bulk, and if kept dry they remain unchanged for years. The nutrients are readily digestible, and the ratio of dynamic to thermic energy is therefore high.

The chemical composition of seeds is more constant than that of the vegetative organs, and is fairly characteristic of the kind of plant. The influence of climate and season, soil, manuring, etc., on the composition of seeds is comparatively small; it may be attributed almost entirely to the effect on the ripeness or maturity of the seed.

Imperfect ripening, to whatever cause it may be due, inevitably results, in the case of cereals, in deficiency of starch. Under these conditions the grain contains a larger percentage of nitrogenous matter, but a considerable proportion of it is not properly elaborated as protein; the amount of amides is, therefore, abnormally large.

The most important of the seeds used as feeding stuffs are the cereals, including rice and maize, pulse, *e.g.* peas and beans, and the oil-bearing seeds, *e.g.* linseed, cotton seed.

The various cereals closely resemble each other in chemical composition. They are essentially starchy seeds. The dressed grain always contains over 50 per cent. of that ingredient, and not infrequently over 70 per cent. The amount of fat is necessarily small; with few exceptions it rarely exceeds about 2 per cent. In average samples the proportion of protein varies from about 10 to 12 per cent. The starch is concentrated towards the centre. The aleurone layer which lies on the outside, just underneath the husk, and the germ situated at one end, are rich in fat and protein; and some of the offal products in which these are included contain more fat and nitrogenous matter than the whole grains.

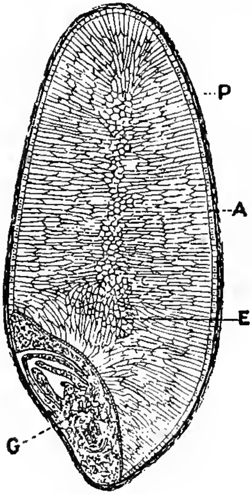
The principal cereals grown in this country are wheat, barley, rye, and oats. Maize, rice, and various millets, which are also included in this class, are imported from abroad in large quantities.

Wheat.—From many points of view wheat is the most important cereal. As, however, it is in great demand as food for human beings, it is not much used for cattle feeding. That it is suitable for that purpose is obvious, and that the animals exhibit a marked relish for it is well known. The question is, therefore, merely, or mainly, one of relative cost. When the price is compared with that of other cereals (p. 167) it will be seen that wheat appears at no great disadvantage. The inferior grades of wheat, which can be obtained at lower prices, can be profitably employed. The various wheat offals are in great demand as feeding stuffs.

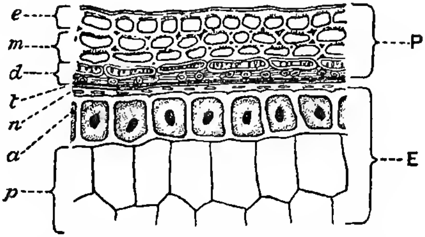
The dressed grain as supplied to the millers consists of three successive membranous or husky coats, forming the pericarp or branny envelope, the highly nitrogenous aleurone layer which lies underneath, and the kernel with the germ at one end (Figs. 18 and 19). This kernel is made up of cells which contain the endosperm, consisting of the nucleus and a mass of vacuolated protoplasm—the wheat gluten. The vacuoles contain the starch granules, and those seeds in which they are more completely filled with starch have the highest weight per bushel. The average for English wheat is about 62 lbs.

The more nitrogenous samples are harder and more translucent in appearance than those which are more starchy.

In the old-fashioned method of stone-grinding, the outer coats, together with the aleurone layer and a certain amount of adventitious starchy matter, were first removed and sold as bran. The remainder was then ground directly into flour. The innermost portion of the grain was, of course, the last to be reduced; it contains the largest percentage of starch and yields the finest, *i.e.* the whitest, flour.



[1] FIG. 18.—Wheat grain.—Diagrammatic section showing—P, pericarp with testa and nucellus forming the branny envelope; A, aleurone cell layer of endosperm; E, parenchymatous cells of endosperm; G, the germ, or embryo.



[1] FIG. 19.—Cross-section through branny envelope and outer portion of endosperm × 100, showing—P, pericarp, consisting of (*e*) epicarp, (*m*) mesocarp, and (*d*) endocarp; E, endosperm consisting of (*a*) aleurone cells and (*p*) parenchymatous cells; (*t*) testa, (*n*) nucellus.

In the modern mills the stones are replaced by metal rollers, of which there are several sets; elaborate methods of sifting and fanning are employed and many different products are or may be obtained. The grain is not directly ground to flour, but is first broken into pieces which are separated as far as possible from the husks and aleurone portion.

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[1] L.G.B. Food Reports, No. 14 (Cd. 5831). By permission of the Controller of His Majesty's Stationery Office.

In the four-break system, now generally employed, the grain is first broken into halves. These are then passed successively through two other sets of rollers by means of which the endosperm is separated from the outer portion and broken into smaller pieces. These fragments of the wheat kernel are technically known as semolina.[1] They are sifted and graded and finally ground into flour, of which at least two qualities—seconds or baker's flour, and patents or finest white flour—are generally produced. The germ is usually removed in the course of grinding the semolina.

In each of the first three breaks a certain amount of the endosperm is inevitably reduced to the condition of flour. This is separated from the semolina by sifting and fanning, but as it contains a considerable amount of husky matter and some of the aleurone portion, and these are not easily eliminated, it is treated as offal, *i.e.* it is sold for cattle feeding under the name of fine pollards, middlings, or toppings.

The fourth or last break has for its object to clean out the remains of the endosperm from the skins of the grain as thoroughly as possible. The latter is separated and sifted into two grades known respectively as coarse pollards or sharps and bran. The three offals differ from each other chiefly in regard to the relative proportions of endosperm, skin, and husk which they contain. Middlings or toppings is the finest, and bran the coarsest.

The chief products of wheat milling may be tabulated as follows :—

Wheat grain	Offals	Bran. Coarse pollards or sharps. Fine pollards, middlings, or toppings.
	Germ.	
	Semolina	Seconds, baker's, or ordinary household flour. Patents, or finest white flour.

The roller mills yield a larger percentage of the more

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[1] The breakfast cereal commonly sold under that name is an entirely different product. It is prepared from certain special, hard, *i.e.* highly nitrogenous wheats, the flour of which is mixed to a paste with water, dried and then ground to a coarse meal. It is, in effect, unmoulded macaroni or spaghetti.

profitable flour than the old-fashioned method of stone grinding. The actual yield, of course, varies both with the kind of wheat and the method employed; but in general, 100 lbs. of grain yield from 70 to 75 lbs. of flour, of all qualities, and from 25 to 30 lbs. of offals of all kinds.

Barley.—The structure of the grain resembles that of wheat, but the process of milling to which it is subjected is very different. In this case the object is to remove only the husk and outer layers without breaking the grain. The outer coat, which is first removed, is known as "coarse dust." It consists almost entirely of husk, and is of little use for feeding. The second or under layer, called fine dust or barley bran, is much richer in nitrogenous matter and fat. It is a valuable feeding stuff, but the supply is not plentiful. The kernel which remains is known commercially as "pot barley." By further treatment it is reduced to "pearl barley," and the offal obtained in this process is known as pearl dust. It corresponds approximately to wheat middlings and contains a considerable amount of starchy matter.

Barley is used to a considerable extent—usually in the form of a coarse meal—as a feeding stuff. It has been found peculiarly suitable for fattening pigs, but may also be given to other animals. The wide differences often noticeable in statements of the composition of barley may be attributed mainly to differences in the samples. Larger amounts of husk appear to have been included in some cases than in others.

The best qualities of barley are chiefly used for malting and the malt coombs or dust, *i.e.* the sprouts of the germinated seeds, and the residues from breweries and distilleries (*q.v.*) are of perhaps even greater importance as feeding stuffs than the barley grain itself. The high price of malt precludes the use of this stuff for feeding; but when large amounts of starchy foods are given to fattening animals, the addition of a little malt has proved beneficial. It probably renders the starch more easily digestible, but it has a rather laxative effect.

Rye.—At prices now prevailing, rye is the cheapest of the home-grown cereals. There is, however, a certain prejudice against it. It is said to have a deleterious influence on the quality of butter, and also that it is liable to prove injurious to the health of the animals, especially horses. The same, however, is true in greater or less degree of all cereals when new.

Oats.—The weight per bushel—the usual test of quality in cereals—of oats varies from about 35 to 48 lbs. These limits are much wider than in the case of other corn crops, and the fact has been attributed to the variation in the thickness and proportion of the husk and skin. Those which have the highest weight per bushel—about 45 lbs. and upwards—are used for making oatmeal. The husk is valueless for feeding purposes, but the other offal, called oat bran, contains about 50 per cent. of carbohydrates, and is therefore useful when it can be obtained.

The chemical composition of oats differs markedly from that of the other cereals. Oats contain about three times as much fat, more fibre, and a smaller percentage of starch. The peculiar "nutty" taste, which is characteristic of this grain, has been ascribed to the presence of .a small proportion of free fatty acid, which is, of course, included in the ether extract. The coefficients of digestibility also are generally somewhat lower than in wheat and barley.

The lighter varieties and qualities of oats are generally given to the horses, for which it is the food par excellence. The animals exhibit a preference for this grain above all others, and there is a universal consensus of opinion that it "puts more spirit into them." This has been attributed to the presence of a peculiar protein to which the name avenine[1] has been given. It is probable that the peculiar stimulating effects of oats are due to the nitrogenous matter, and that the substance belongs to the protein group, but it has not been isolated or described.

New oats tend to produce colic and inflammation of the

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[1] The name "avenine" is now given to one of the proteins of oats (p. 74), but this is not the hypothetical substance above referred to. At least it it not known to have the properties described in the text.

bowels in horses, but this effect is not noticeable when the grain has been stored for two or three months. To what cause this is due or what changes take place on storing are unknown.

Maize or Indian Corn.—The climate of this country is not suitable for the growth of maize, but large quantities are imported from abroad. The grains are found arranged in rows upon a cylindrical "cob" as shown in the illustration[1] (Fig. 20). The latter consists chiefly of hard lignified cellulose. It is very difficultly digestible and of little use for feeding purposes. The dried cobs are sometimes broken up and mixed with other foods — otherwise the cattle will not touch them—and they may serve to some extent for maintenance of ruminants, but are bound to reduce the digestibility of the other foods.

The grain, when separated from the cob, is extremely hard, and is, therefore, generally ground to a fine meal, in which condition it is much

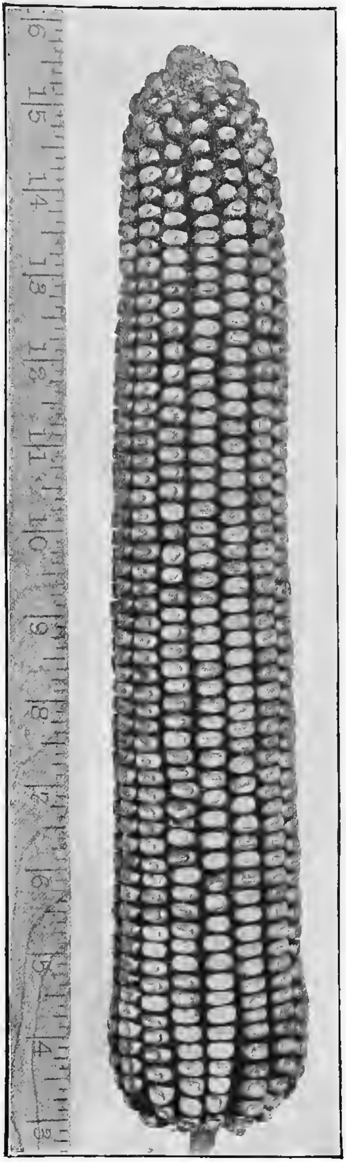

Fig. 20.—"Chester County." From "Maize," by J. Burtt-Davy.

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[1] The variety illustrated, known as "Chester County," is described as an excellent type of yellow maize for stock feed.

appreciated by nearly all farm animals. It is very useful for fattening, and also, when mixed with other, more nitrogenous, substances, for milk production, etc. Excessive quantities should not, however, be given to pigs, as it is said to produce an inferior quality of bacon. The coefficients of digestibility are very high. The demand for this article has much increased of late years, and the price has risen considerably. It is still, however, one of the cheapest of the starchy products on the market.

Rice Meal.—The structure of the rice grain resembles that of wheat and barley, and the milling process to which it is subjected is similar in effect to that employed in the case of the latter. The husk is of little or no value for feeding purposes, but the underlying coat which is next removed is very suitable, and is known as rice meal. It contains a fair amount of protein and is rich in oil and carbohydrates. In genuine samples there is only a small percentage of husk; but rice husks ground and mixed with broken and damaged grains are often sold as rice meal. For some reason rice meal is not much appreciated by farmers in this country, and the price is consequently low. Having regard to the nutrients it contains, it is, at present rates, cheaper than maize (cf. pp. 167, 213).

Leguminous Seeds.—Compared with the cereals, the leguminous or pulse seeds are distinguished by the high percentage of nitrogenous matter and small amount of carbohydrates which they contain. In peas and beans, the percentage of fat is no greater than in the common cereals, but some leguminous seeds, *e.g.* soyabean and earthnut, contain large amounts. These are, therefore, conveniently regarded as oily seeds although, botanically, they belong to this order. The coefficients of digestibility are generally somewhat lower than in the case of the cereals, and a larger proportion of the nitrogenous matter is not true protein.

Certain leguminous seeds, *e.g.* Java beans, though rich in nutrients, cannot be used as feeding stuffs because they contain nitrogenous glucosides which, on contact with the digestive juices, undergo hydrolysis with the formation of the deadly poisonous prussic acid.

All leguminous seeds are more or less binding in their effects, and in large quantities they give rise to febrile symptoms. They are chiefly useful for mixing with maize and other starchy foods so as to raise the albuminoid ratio. They are employed in this manner in the rations for milk cows, and, to a certain extent, as a partial substitute for oats in the rations of working horses.

Oily Seeds.—With the exception of linseed (flax seed) these seeds are not used in their natural state for feeding cattle. The high value of the oil they contain makes the price prohibitive. Linseed, however, is used to a considerable extent for feeding newly weaned calves. For this purpose it is boiled with water and allowed to cool. The mucilaginous carbohydrate which it contains swells up, forming a practically homogenous mixture which sets as a jelly on cooling. This is much appreciated by the young animals, and is considered one of the best substitutes for milk.

Oil Cakes.—The oil is generally obtained from oily seeds by subjecting them to great pressure. The compressed residues are known as oil cakes. They still contain some of the oil and all the other nutrients originally present in the seed. In fact, the percentages of these ingredients in the cake are much greater than in the whole seed; for they are increased in proportion as that of the oil is diminished. Oil cakes are, therefore, very rich and valuable feeding stuffs. Originally a by-product, they are now probably as great a source of profit as the oil itself. They are distinguished by the name of the seed from which they are produced, and English law requires that they should be pure.

The method of manufacture is much the same in all cases. Briefly, it is as follows: The seed, after it has been cleaned and purified by screening, is ground to a coarse meal. This is slightly moistened with water, crushed under heavy rollers, and then heated in a steam kettle to 100° C. Measured quantities, according to the size of cake to be produced, are introduced into woollen bags and placed between wooden or iron moulds in the press. While the temperature remains at about 50° C., pressure of about a ton to the square inch is applied by means of a hydraulic ram or other device; the oil flows out and is collected in tanks constructed to receive it. When the pressure is relaxed, after about ten minutes, the residual cake is removed. It has the shape of the bag and bears on its surface the impression of the mould—generally the name or trade mark of the manufacturer—in which it was made. As it comes from the press it is still hot and steamy, and must be placed in a rack for a few days to dry and harden. If not properly dried the cakes are liable to mildew and become unfit for use as food.

Linseed Cake.—Flax is rarely grown for seed in this country. The bulk of the seed comes from Russia and India. Russian linseed cake commands the highest price. It is generally purer and richer in composition. Bombay linseed cake is rather lighter in colour, and not infrequently contains foreign seeds—chiefly rape and occasionally mustard. The latter has a certain irritant effect on the alimentary canal, but it is probably not so dangerous as it was at one time thought to be. Its presence is, however, undesirable, and it is easily separated from linseed by screening.

All genuine linseed cakes, when properly made, have a reddish grey colour. A dark appearance is regarded as an indication of overheating. Adulteration with starchy cereals gives them a lighter colour. This can easily be confirmed by the iodine test (p. 25). Genuine linseed contains neither starch nor sugar in perceptible quantity; the soluble carbohydrate is almost entirely mucilaginous in character. A small quantity of the ground cake when boiled with water should form a jelly on cooling. The presence of sugar can be detected by Fehling's test (p. 19). Foreign seeds, husks, straw, etc., if present, may be seen under the microscope.

For many years linseed cake has been regarded by farmers as one of the safest and most satisfactory foods on the market. The recent discovery of the presence in the seeds of a nitrogenous glucoside which, on hydrolysis, yields prussic acid, has naturally caused some misgivings in regard to it. Since then several cases of poisoning have been ascribed to linseed cake, and there is reason to believe that others may have occurred previously.

The glucoside was named "linamarin"[1] by Jorissen, the discoverer, but it was subsequently found to be identical with the phaseolunatin of Java beans previously referred to. The substance itself is said to be harmless, but on maceration with water it undergoes decomposition as shown in the following equation:—

$$\underset{\text{(Glucoside.)}}{C_{10}H_{17}O_6N} + H_2O \rightarrow \underset{\text{(Dextrose.)}}{C_6H_{12}O_6} + \underset{\text{(Acetone.)}}{(CH_3)_2CO} + \underset{\text{(Prussic acid.)}}{HCN}$$

The change is caused by a coexistent, specific enzyme, and it takes place most rapidly at or about the temperature of animal bodies. When heated to 100° C., the enzyme is destroyed or rendered permanently inactive; and as this generally forms part of the ordinary process of manufacture of linseed cakes (*vide supra*), no danger is to be apprehended. In some cases, however, the seed is pressed cold, or at a lower temperature, and a certain risk attends the use of cakes made in this way.

The quantity of potential prussic acid in linseed cakes varies from 0 up to about 0·05 per cent. It is estimated that about one-third of a pound of the cake containing the maximum amount would poison a sheep, and that from 2 to 3 lbs. would poison an ox. Cakes containing the maximum quantity mentioned above are, however, comparatively rare, and authenticated cases of poisoning by linseed cake are few. Even if the hydrolytic enzyme be not entirely destroyed in the process of manufacture, it has been found that most other foods, *e.g.* hay, green fodders, molasses, salt, etc., tend to inhibit its action, but those which contain yeast, malt, or moulds, tend to promote the action.

The risk of prussic acid poisoning is much greater when whole linseed or linseed meal from which the oil has been extracted by means of solvents at a low temperature are used. In these cases the enzyme is not destroyed, and when they are masticated or made into a mash or gruel with warm water, the conditions are very favourable to its action. Such gruel

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[1] Auld, Report of Chem. Dept. S.E. Agricultural College, Wye, 1912.

is generally given only to young or sick animals, and then it usually forms a large proportion if not the whole of the ration. The cake is usually fed in a dry state to healthy adults, and only small quantities are used. If the mash is made with *boiling* water and kept as hot as possible for an hour or two before it is used, the enzyme will probably be rendered inactive, and danger is reduced to a minimum.

Nitrogenous glucosides which yield prussic acid on hydrolysis have also been found in the seeds of many other plants, amongst which may be mentioned the great millet, Java beans, Cassava, vetch, and the Para rubber plant. Oil is extracted from the last, and the residue is sold as a feeding cake.

Cotton Cakes.—The seed of the cotton plant contains the woolly cellulose fibre which is spun and woven into ordinary cotton. It belongs to the class of oily seeds, and, when the cotton has been removed, the oil is expressed, and the residue is sold for cattle feeding under the name of cotton cake. There are several varieties of this product, and they differ greatly in composition and properties according to the treatment to which the seed is subjected. In America, the hull or cortex of the seed is first removed. This permits of a very complete separation of the cotton, and the cake which remains when the oil has been expressed, contains little but the actual nutrients of which it is composed. It is known as American or decorticated cotton cake. It is one of the most highly concentrated, most readily digestible, and, at present rates, one of the cheapest cakes on the market (cf. pp. 166, 213). With the possible exception of linseed cake, probably none are more appreciated by the animals.

The Egyptian and Indian (Bombay) seeds are treated in a different manner. The cortex is not removed, and the cotton cellulose cannot be completely extracted. Undecorticated cotton cakes—the deoiled residues—therefore contain nearly three times as much crude fibre, and only about half the percentages of oil and albuminoids commonly found in the American cakes. The coefficients of digestibility and nutritive value are consequently much lower.

Undecorticated cotton cakes are sold at lower prices per ton, but at present rates the price per unit is higher than is charged for the decorticated cakes. Having regard to the proportions of crude fibre in them, the former is probably worth considerably less per unit than the latter. Undecorticated cotton cakes have, however, a certain binding tendency which makes them very suitable for cows at grass.

When the animals are on dry feed the woolly cotton cellulose is apt to "ball" and produce stoppage of the bowels. The Bombay cake is generally much worse in this respect than the Egyptian; but the latter often contains more of the hard hulls. Both varieties are unsuitable for young stock, and if given in large quantity may set up inflammation.

Soyabean Cake.—In the last few years cakes made from Soy or Soja beans have been put on the market, and have met with a favourable reception. In general character they resemble decorticated cotton cake, but are said to be laxative rather than binding. Certain farmers of the writer's acquaintance have declared that Soya cakes have a strongly purgative effect, but such does not seem to have been the common experience. Good results have been obtained, and the majority of farmers seem to think that these cakes will become permanently established on the market. At present, Soya cakes command about the same price as decorticated cotton cakes; but, judged by chemical composition they are, as a rule, not worth quite so much.

Rape Cake.—Rape or colza seed is grown in Germany, Austria, Russia, and India, chiefly for the sake of the oil. The cake resembles linseed cake in composition and general properties, but is easily distinguished by its colour and odour. Though at one time highly esteemed, it has now fallen into disfavour in this country, probably because it was generally impure and not infrequently it was deliberately adulterated. Mustard and other foreign seeds, sand, gypsum, and other impurities were often present. Rape cake is still used on the continent, where it can be obtained at low prices (cf. pp. 166, 213). In England the rape oil is now to a large extent extracted by means of solvents, and the residual meal is used as manure.

These remarks are also applicable in large measure to niger cake, hempseed cake, and seasame cake. They resemble rape cake more or less closely in composition and general properties, but are now difficult to obtain.

Earthnut Cake.—When made from decorticated seed, earthnut, or ground-nut cake compares favourably with decorticated cotton cake in composition, and is, usually, not inferior in other respects. It is very similar to the latter in general properties, and may be used for the same purposes. The greater concentration of the nutrients in the earthnut cake is, of course, of no particular advantage to the purchaser unless it can be obtained at the same or a lower price. The undecorticated variety of earthnut cake is now comparatively rare. It contains a considerable amount of fibre, and is necessarily much inferior, weight for weight, to the other. These cakes never became very popular in this country, and are not easily obtainable.

Cocoanut Cake.—In recent years there has been an increased demand for cocoanut oil. It is expressed from copra, the dried fleshy part of the nut, and larger quantities of cocoanut cake have been put on the market. The cake exhibits the characteristic flavour and odour of the nut, and when fresh it is relished by the animals. The oil, however, rapidly goes rancid, and becomes very distasteful.

Palmnut Cakes.—Palm oil is expressed both from the fleshy part of the nut which surrounds the kernel and from the kernel itself. The cake produced from the latter should be distinguished as palmnut kernel cake, but the two parts are often crushed together. These cakes have a somewhat rank but not altogether disagreeable flavour. As in the case of cocoanut cake, however, the oil is apt to turn rancid.

Cakes made from poppy seed, sunflower seed, indigo seed, etc., are occasionally offered for sale, but not often in this country. Mustard cake and castor cake should not be used for feeding. Acorns and beechnuts are also undesirable. They both contain considerable quantities of tannin or other bitter, astringent principles which inhibit or retard the processes of digestion.

When the oils are extracted from seeds by means of solvents, the residual meals are sometimes pressed into the form of cakes. Such cakes always contain a smaller percentage of oil than the genuine oil cakes described above, but they are, of course, richer in other ingredients. The meals are, however, generally sold in the loose condition. Their composition is similar to that of the cakes made from them.

Compound Cakes and Meals.—The distinction between oil cakes and compound cakes is an important one. The former consists essentially of the pressed residues obtained from oily seeds and nuts. English law requires that they must be made from the seed or substance by the name of which they are marketed, and from nothing else. The latter—compound cakes—usually consist of a mixture of seeds of various kinds, starchy meals, pollards, hay, straw, husks, and other similar substances, pressed into the form of a cake. They can, therefore, be sold at much lower prices than oil cakes. Their popularity probably depends on this in conjunction with a lingering notion that there is virtue in the fact that they are cakes, *i.e.* that they necessarily possess some of the qualities of oil cakes. There is no such necessity. As cakes they may be more convenient for storing and handling, but in point of composition they are to be regarded merely as pressed mixed meals. The latter, in the unpressed condition, possess the advantage that they do not need to be broken for use.

Compound cakes and meals are usually called by some name, *e.g.* "dairy cake," "fattening meal," etc., intended to imply that they are peculiarly suitable for certain purposes. Analyses showing the percentages of crude nutrients are frequently quoted in support of such contentions; and it may be said that the guarantees given by firms of repute are generally trustworthy.

It is, perhaps, scarcely necessary to repeat what has been said so often before, viz. that the amounts of crude nutrients in a feeding stuff afford little or no information as to its nutritive value unless the nature and proportions of the ingredients from which they are derived is known. For example, hay of average quality contains about 10 per cent. of total nitrogenous matter, and decorticated cotton cake about 40 per cent., but it would be quite wrong to assume that 4 lbs. of the former are equal to 1 lb. of the latter. In hay a considerable amount of the total nitrogenous matter is not true protein; only about half of the latter is digestible, and of the digestible portion a considerable amount is expended in the work of digestion; whereas in the cake it is practically all true protein, a much larger percentage is digestible, and little or none is spent in the work of digestion. If, therefore, any of the nitrogenous matter of a cake is derived from hay, it will be of much inferior value to that derived from seeds.

Apart from these considerations, it is obvious that the suitability of a cake for any particular purpose must depend to a very large extent upon the kinds and quantities of the other foods that are used along with it. If the percentages of digestible nutrients in a cake and in the other foods to be used in conjunction with it are both known, the foods can be adapted to each other by the methods described in Chapter XIV.; but in the absence of such information, it is impossible for the farmer to exercise any scientific control. He must be guided merely by the instinct of the animals and the length of his purse.

Industrial By-products.—The more important industries in which by-products suitable for the nutrition of farm-stock are obtained are malting, brewing, distilling, and the manufacture of starch and sugar. The by-products of the flour mills and oil mills have already been described. The nature of the substances and the probable variation in quality, apart from deliberate adulteration, is best shown by a brief review of the methods by which they are produced.

Malt Dust.—This product, sometimes called "coombs" or "cummings," consists of the dried sprouts of barley grains. The tissues are very young, and in the fresh condition would almost certainly prove extremely soft and readily digestible. They are, however, always dried in order to separate them from the seed and are thereby rendered somewhat harder. Even so, the coefficients of digestibility are high. The percentage of total nitrogenous substance is also high, but a large amount of it is of amide character. The cellulose is probably not at all lignified. It is said that when large quantities are fed to pregnant animals malt dust has a tendency to cause abortion. This is important, as they are chiefly used for milk cows.

Brewer's Grains.—In the process of brewing, the malt is "mashed" with warm water in order that the diastase may act upon the starch and convert it into sugars and dextrine. The operation is conducted so as to extract as much as possible of the soluble carbohydrates and as little as possible of the nitrogenous matter. The residual soft pulpy mass is the brewer's grains. Though saturated with water, it contains from 5 to 6 per cent. of nitrogenous matter, of which the larger part is digestible true protein, about 12 per cent. of soluble carbohydrates, and only a small amount of fibre. This substance is, therefore, a highly nutritious food, and moreover it is very cheap. In fact, in proportion to the amount of nutrients it contains it is the cheapest food on the market. This statement is based on the price at the brewery whence it must be fetched; and, owing to the large amount of water it contains, the cost of haulage is great. The demand is, therefore, practically limited to the farms in the immediate neighbourhood.

At many breweries the grains are now dried. The process costs money, and as the dried grains will bear the cost of railway transport the demand is greatly increased. The price of the dried grains is, therefore, much higher in proportion to the amount of nutrients they contain (cf. pp. 166, 213).

In brewing porter and stout, the malt, or a portion of it, is caramelised so as to produce the black colour. The residual grains have a somewhat bitter flavour, but it is not distasteful, and they have practically the same composition as ale grains.

In the moist condition, brewer's grains cannot be kept for any length of time. They rapidly turn sour owing to lactic fermentation, and soon become mouldy. They are then quite unfit for use. It is said that when large quantities of brewer's grains are fed to cows, the animals do not readily come in season again, and so cannot be got "in calf." Apart from this, there is no question that brewer's grains are a very suitable food for milk cows. The large proportion of nitrogenous matter they contain is favourable for milk production.

Slump.—Distillery grains when made from malt are very similar to the product obtained from breweries. In some cases, however, the practice is very different. Other things besides malt, *e.g.* rice, maize, rye, potatoes, molasses, etc., are introduced into the mash, yeast is then added, and the whole is afterwards distilled directly, *i.e.* without first drawing off the liquid. The residue which remains in the retorts, therefore, contains everything except the carbohydrate that has been converted into alcohol. It is known as distillery waste or slump. It varies greatly in composition and character according to the nature of the materials and the treatment. When it includes potatoes, or molasses, it is scarcely fit for use as food. The yeast is of course rendered inactive by the distillation, and its presence increases the percentage of digestible nitrogenous matter in the product. Dried slump can also be obtained.

Gluten.—This is a by-product obtained in the manufacture of starch. Wheat, rice, maize, and potatoes are all treated in different ways, and the by-products vary in composition and character.

In the case of wheat, the flour is first mixed to a thin dough and then worked with water on fine sieves until practically all the starch is washed out. The residue which remains on the sieves consists of nearly pure wheat gluten. It is dried and sold in a flaky condition.

"Rice gluten" is dissolved by soaking with dilute alkalis, and is reprecipitated with acids. The husks, from which the starch is washed out with water, are also sometimes sold as feeding stuff under the name of "rice sludge."

In the case of maize, the grain is ground to flour in a current of water. The husks or skins rise to the surface and the germs sink to the bottom. The starch and gluten, which are carried off by the current, are separated by sedimentation. The latter, when dried and ground up, is sold as gluten meal. The germs are collected and treated in a similar manner and sold as maize-germ meal, or, pressed into the form of a cake, as maize-germ cake.

Sometimes the gluten, germs, and husks are mixed, dried, and ground up together, and the product is called "gluten feed." The composition of the last-mentioned substance is very variable. It depends chiefly upon the proportion of husks that are included. Bran, rice sludge, and other foreign materials are occasionally mixed with it in different proportions. These products are sold under various fancy names. Wheat gluten is often used up in a similar manner.

In the manfacture of starch from potatoes, the cells of the tubers are ruptured by machinery, and the starch is washed out with water as far as possible. As it is only possible to remove about half the total starch in this way, the residual sludge when dried is fairly rich in carbohydrates. It is practically destitute of nitrogenous matter and fat. The nutritive value of potato sludge is, therefore, much inferior to the gluten products obtained from wheat, rice, and maize. The latter contain large percentages of protein and carbohydrates, and also a certain amount of fat.

Molasses and Sugar Feeds.—Ordinary household sugar is prepared from sugar cane and sugar beet. In both cases the material is reduced to pulp, and the sugar extracted in aqueous solution. This solution is concentrated by evaporation in vacuum pans and the sugar is crystallised out. A considerable amount of sugar, however, remains in an uncrystallisable condition and forms the black viscous liquid called molasses or treacle. The uncrystallisable sugar has the same nutritive value as that which crystallises, and it forms about 60 per cent. of the total residue, treacle.

Cane sugar molasses is used as food for human beings; that obtained from beet is more impure, has a strong bitter taste, and is not fit for this purpose. It is, however, used in large and increasing quantities for cattle feeding. Apart from water, the impurities consist mainly of amides and potash salts.

As both of these are liable to interfere with the processes of digestion and derange the health of the animals, treacle can only be given in limited quantities. Though of little or no nutritive value, the amides and potash salts tend to enrich the manure. This fact should not be overlooked, as it might be, for molasses is rightly regarded as a purely carbohydrate food.

The best way to use this substance is to dilute it with hot water and mix the solution with other foods, *e.g.* hay or straw, maize, etc. The sweet flavour is greatly relished by the cattle, and treacle may be used as a condiment for food that is otherwise not very appetising. It should never be used, however, to induce cattle to consume food that has become mouldy, decayed, or otherwise unfit for use.

Materials of this kind can now be obtained ready prepared. They are called molasses meals, sugar feeds, or by some fancy name. The condition in which they are sold is usually that of a slightly moist but friable meal or powder, which is more convenient to handle than the viscous liquid. The absorbent material most commonly used is peat. This substance is not only of no nutritive value in itself, but probably lowers that of the molasses mixed with it. Chaff, husks, and similar substances are sometimes used instead, and such samples are generally guaranteed to contain no peat. The nutritive value of these substances is very little, if at all, superior to that of peat, and they are very liable to be infected with moulds or other deleterious fungi. The amount of absorbent material required to produce a fairly dry meal is, however, relatively small and, as the products are not used in large quantities at a time, it probably does little harm. These meals usually contain from 40 to 50 per cent. of sugar, and should be valued solely according to the amount of that constituent.

Locust or Carob Beans.—This feeding stuff consists of the whole fruit or pod containing the seeds or beans proper. They are grown chiefly in the island of Cyprus, and are dried after being harvested. They contain about 50 per cent. of sugar and from 15 to 20 per cent. of other "soluble" carbohydrates. They are relished by cattle on account of their pronounced sweet taste. Even when thoroughly dried they contain about 15 per cent. of moisture, and they readily absorb more. It is essential, therefore, that they should be kept in a dry place, otherwise they rapidly turn mouldy and become unfit for use.

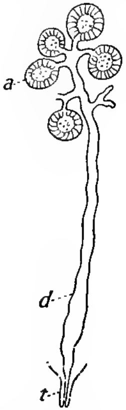
Acorns and Beechnuts.—Like all fruits and seeds, acorns and beechnuts contain considerable quantities of nutritive substances, but owing to the large amount of tannin or other astringent constituents, they are practically unfit for use, and should not be given to valuable stock. The small quantities which the animals pick up in the fields, when they have plenty of other food, probably do no harm, but they should not be forced to consume large quantities of such astringent substances.

PART IV.—DAIRYING

CHAPTER XVIII

COMPOSITION AND GENERAL PROPERTIES OF MILK

Secretion.—The external appearance of the cow's udder, or mammary gland, with the four teats from which milk is drawn, is familiar to the most casual observer. Internally, the structure of the gland is extremely complex. The relation of the more important functional parts is shown in the diagram[1] (Fig. 21). The teats are tubular, and the ducts are irregularly expanded above, forming cisterns, or reservoirs, in which the milk accumulates. At a further point the ducts branch, and the innumerable smaller ducts which lead off from them terminate in small, pouch-like structures called alveoli. It is in these that milk is actually formed.



a---*Alveoli.*
d---*Lactiferous duct.*
t---*Teat.*

FIG. 21.

The cavity of each alveolus is lined with a single layer of secreting cells. When the gland is active, *i.e.* when the cow is "in milk," these cells become enlarged, and the pressure of the contiguous cells causes them to protrude into the cavity. In this condition, each cell contains two or more nuclei. The innermost nucleus is generally normal in size and appearance. Those which are nearer to the free end of the cell are irregular in outline, and exhibit other signs of degeneration. The cells also contain water, salts, sugar, fat, and protein bodies, all, it

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[1] After Percival, "Agricultural Bacteriology."

is believed, derived from the degeneration of the nucleus above referred to. These contents are, in time, discharged into the cavity of the alveolus, and the mixture forms what we know as milk.

It will be seen that milk is not directly secreted from the blood, like saliva or urine. The process is to be regarded rather as one of disintegration of the cellular substance of the gland itself. The latter is reformed out of the materials derived from the lymph (the blood plasma which exudes through the thin walls of the capillary vessels), and the process is repeated indefinitely. Leucocytes (white blood corpuscles) occasionally find their way from the blood into the milk; but none of the normal constituents of milk are derived *directly* from the blood.

The organic constituents of milk do not occur ready formed in the blood. They must, therefore, be produced in the gland. The same inorganic (ash) constituents occur in both, but they are present in different proportions in the two fluids. Blood, for instance, contains about 0·42 per cent. of soda, and only 0·056 per cent. of potash, whereas milk contains about 0·13 per cent. of the latter, and only 0·07 per cent. of the former.

It follows from these premises, *i.e.* that milk is derived from the substance of the gland and not directly from the blood, that the yield and quality of the milk cannot be directly influenced—or only to a limited extent—by the food of the animal (cf. p. 176).

Chemical Composition.—The more important compounds which enter into the composition of milk are water, fat, proteins (nitrogenous matter), milk-sugar, and the "mineral salts," or ash. The actual and relative proportions of these constituents fluctuate within certain ascertained limits, presently to be discussed. The average composition of the milk obtained in England, Germany, and America is given in the following table:—

	Richmond.[1]	Fleischmann.[1]	Snyder.[1]
	Per cent.	Per cent.	Per cent.
Water	87·20	87·75	87·50
Fat	3·90	3·40	3·60
Nitrogenous matter	3 40	3·50	3·40
Milk sugar	4·75	4·60	4·75
Ash	0·75	0·75	0·75
	100·00	100·00	100·00

It will be seen that there is but little difference, except in regard to the percentage of fat, which is by far the most variable constituent.

According to Vieth, the average ratio between the milk-sugar proteins and ash is as 13 : 9 : 2; and this is confirmed by Richmond.

The highest and lowest percentages of the several constituents in the mixed milk of large herds are given as follows:—

	Fleischmann.		Snyder.	
	Highest.	Lowest.	Highest.	Lowest.
	Per cent.	Per cent.	Per cent.	Per cent.
Water	89·5	87·5	87·82	84·76
Fat	4·3	2·7	6·50	3·45
Nitrogenous matter	4·0	3·0	4·20	3·00
Milk sugar	5·5	3·6	5·25	4·30
Ash	0·9	0·6	0·78	0·60

For the milk of individual cows taken at one milking, and under different circumstances, the limits of variation are naturally much wider, as shown in the following table:—

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[1] Richmond's figures represent the average of some 200,000 samples analysed in the laboratory of the Aylesbury Dairy Company. Those of Snyder were deduced from analyses of 3000 samples, reported in the bulletins of the agricultural experiment stations of the various American states. Fleischmann's figures represent the average composition of the day's milk of large herds (75 to 150 cows) in various parts of Germany.

	Kirchner.		American.	
	Average.	Limits of variation.	Average.	Limits of variation.
	Per cent.	Per cent.	Per cent.	Per cent.
Water	87·5	From 83·00 to 90·00	87·00	From 81·1 to 91·4
Fat	3·9	,, 0·80 ,, 8·00	4·00	,, 2·0 ,, 8·0
Nitrogenous matter	3·4	,, 2·28 ,, 5·73	3·30	,, 2·0 ,, 4·5
Milk sugar	4·5	,, 3·00 ,, 6·00	4·95	,, 4·0 ,, 5·5
Ash	0·7	,, 0·60 ,, 0·90	0·75	,, 0·6 ,, 0·9
Total solids	12·5	,, 7·2 ,, 12·63	13·00	,, 8·6 ,, 18·9

The average composition of the solids, calculated from Fleischmann's figures, is as follows:—

	Per cent.
Fat	27·75
Nitrogenous matter	28·57
Milk sugar	37·56
Ash	6·12
	100·00

Legal Standards.—In this country, the legal standard for genuine whole milk is 3 per cent. of fat, and 8·5 per cent. of non-fatty solids. If the milk is not up to that standard, *i.e.* if it contains less than these amounts of fat and non-fatty solids, it is assumed in law that some of the fat has been removed, or that water has been added, until the contrary is proved. The onus of proof rests with the vendor.

The following formulæ, based on the above standards, may be used to calculate[1] the percentages of fat removed and

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[1] EXAMPLES.

	Percentages found on analysis. Fat.	Non-fatty solids.
Sample I.	2·1	8·6
,, II.	3·2	8·0
,, III.	1·9	8·1

I. $100 - \frac{2{\cdot}1 \times 100}{3} = 30{\cdot}0$ per cent. of fat removed.

II. $100 - \frac{8{\cdot}0 \times 100}{8{\cdot}5} = 5{\cdot}9$ per cent. of water added.

$$\text{III.}\begin{cases}(a)\ 100 - \dfrac{8{\cdot}1 \times 100}{8{\cdot}5} = 4{\cdot}70 \text{ per cent. of water added.}\\[2ex](b)\ 100 - \dfrac{1{\cdot}9 \times (100 + 4{\cdot}71)}{3} = 33{\cdot}7 \text{ per cent. of fat removed.}\end{cases}$$

of water added. F and S are respectively the percentages of fat and non-fatty solids found on analysis.

$$\text{Percentage of fat removed} = 100 - \frac{100F}{3}$$

$$\text{Percentage of added water} = 100 - \frac{100S}{8{\cdot}5}$$

When the milk is both watered and skimmed, the formula for the fat removed becomes as follows (W is the percentage of added water):—

$$\text{Percentage of fat removed} = 100 - \frac{(100 + W)F}{3}$$

In many of the American states the minimum required by law is 9 per cent. of non-fatty solids and 3 per cent. of fat. In some cases it is 9·5 per cent. of the former, and 3·5 per cent. of the latter.

Causes of Variation.—The Channel Island breeds of cows are distinguished above all others by the richness of their milk. That of Jersey cows often contains as much as 15 per cent. of total solids, including 5 per cent. of fat. On the other hand, the milk of certain breeds—especially those which, like the Fresian Holstein, give exceptionally large yields—is generally of inferior quality. The composition of the milk cannot, however, be regarded as characteristic of the breed of cow. The differences are too small, and they are often obscured by fluctuations due to other causes. The difference in the composition of the milk of two cows of the same breed, apparently normal and similar in all respects, is often greater than the difference observed in the milk of cows of different breeds.

These remarks may be illustrated by reference to the following figures,[1] which are said to represent the average composition of the milk of various British breeds of cows.

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[1] Bell.

Breed.	Total solids.	Fat.	Non-fatty solids.
Ayrshire	13·46	4·24	9·22
Jersey	14·65	5·43	9·22
Guernsey	14·46	5·16	9·30
Kerry	13·54	4·67	8·87
North Devon	13·11	3·43	9·68
Shorthorn	12·78	3·92	8·86
Sussex	12·31	3·39	8·92
Welsh	13·55	4·40	9·15

The composition of the milk of any given cow varies according to the stage of lactation and time of milking; and it may also be affected, in greater or less degree, by the age, health, and condition of the animal.

It was previously shown (p. 178) that the composition of milk is not directly affected to any considerable extent by the food of the animal; and the fact has been quoted in support of the view that milk is not directly secreted from the blood.

Many practical dairymen believe that the youngest cows give the richest milk, but this has not been confirmed. In fact, some of the evidence points to an opposite conclusion. At present it is uncertain whether the age of the cow affects the composition of the milk at all. If it does, it is probably only to a very slight extent. It is generally agreed, however, that the yield increases each time the cow "comes in" up to the sixth or seventh calf, and that after that it tends to decline again.

The health of the animals may affect the composition of the milk to a considerable extent. When they are sick, the milk is almost invariably of poorer quality than under normal circumstances. The percentage of fat, and sometimes also—but more rarely—of non-fatty solids, is diminished. Similar effects are often produced by excitement, as when the cows are taken to shows and fairs; and also when they are in heat.

The period of lactation, *i.e.* from the date of calving until the cow goes dry, is generally about ten months. During the first two or three months the yield is usually well maintained—it may even increase to a maximum during that time—but afterwards it steadily declines, and towards the end it becomes very small (cf. p. 177). Any increase in the yield during the first three months or so is generally accompanied by a slight reduction in the percentages both of fat and of non-fatty solids. When the yield diminishes as the stage of lactation advances, the percentages of both ingredients, but especially that of the fat, gradually increase again. As a rule, the milk is richer towards the end of the lactation than at the commencement.

When the udder is full of milk it becomes distended, and pressure is set up. This pressure retards the rate of secretion, and also affects the quality of the milk. The rate of secretion is fastest soon after the cow has been milked, and gradually becomes slower as the udder fills. Consequently, the oftener a cow is milked the larger is the total yield obtained. It is said that the yield may be increased 20 per cent. by milking three times a day instead of twice.

The pressure set up by distension of the udder causes increased resistance to the passage of the fat through the gland, and milk secreted under pressure is poorer in quality. Frequent milking tends to reduce the pressure in the udder, and, therefore, produces richer milk as well as more of it.

When cows are milked at equal intervals of, say, twelve hours, no appreciable difference in the composition of the morning and evening milk is observed. When the intervals are unequal, the milk obtained after the longer interval is larger in quantity, but inferior in quality, as compared with that obtained after the shorter interval. This is probably due to the same cause—the increased pressure due to the accumulation of milk in the gland. In town dairies the cows are generally milked about 5 a.m. and 2 p.m., making two intervals of nine and fifteen hours' duration respectively. Consequently, the evening supply is nearly always the richer, but the yield is smaller.

The milk obtained in the course of any one milking is not of uniform quality throughout. Each successive portion contains a higher percentage of fat than the preceding one. The "fore milk," *i.e.* the portion first drawn from each teat, contains less fat than the bulk, and the "strippings," or last-drawn portions, contain more. The magnitude of the differences due to this cause may be judged from the following figures, quoted by Van Slyke :—

FAT IN FOUR SUCCESSIVE PORTIONS OF MILK OBTAINED AT A SINGLE MILKING FROM EACH OF THREE DIFFERENT COWS.

Cow.	First quarter.	Second quarter.	Third quarter.	Last quarter.	Average of bulk.
	Per cent.	Per cent.	Per cent.	Per cent.	Per cent.
I.	0·9	2·6	5·4	9·8	4·6
II.	1·6	3·2	4·1	8·1	4·2
III.	1·6	3·3	5·0	8·3	4·5

It will be seen from the following more complete analyses[1] that the percentages of the other constituents are not appreciably affected :—

	Cow A.		Cow B.	
	First pint.	Last pint.	First pint.	Last pint.
	Per cent.	Per cent.	Per cent.	Per cent.
Water	90·58	80·51	89·90	81·53
Fat	0·71	10·84	1·02	9·49
Nitrogenous matter .	3·44	3·51	3·35	3·65
Milk sugar	4·59	4·42	5·03	4·59
Ash	0·68	0·72	0·70	0·74
Total solids . . .	9·42	19·49	10·10	18·47

It was formerly believed that this phenomenon was due to the natural separation of cream from the milk while standing in the udder. In view of the structure of the milk gland, and the processes by which milk is formed, this hypothesis appears to be untenable. It is more probable that it is due to gradual reduction of pressure as the milk is withdrawn from the udder. This, it has been said, diminishes the resistance and facilitates the escape of the fat globules.

Physical Properties.—The appearance, taste, and odour of milk are familiar. It is commonly described as an opaque,

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[1] Snyder.

white liquid, but it often exhibits a yellow or a bluish tint. A yellow colour is popularly regarded as an indication that the milk is rich in fat, and the dairymen, in towns, generally add annatto to intensify the yellow appearance. As a matter of fact, the yellow colour, if natural, is due to the fat; but, even when very pronounced, it does not necessarily indicate a large percentage of that constituent, nor does the absence of such colour show the contrary. Samples of milk rich in fat are often quite white.

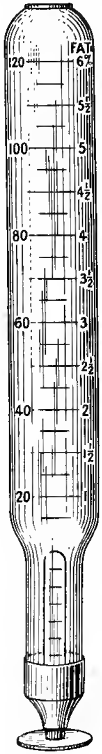

FIG. 22.—Feser's Lactoscope.

When the fat is removed, the blue tint is generally more apparent, and the opacity is reduced. Feser's lactoscope (Fig. 22), for the estimation of fat in milk, is based on this principle, but it does not give accurate results.

The characteristic odour of fresh, warm milk is also due to the fat. When the milk is cold and fresh, the odour is barely perceptible.

The whole of the sugar and part of the mineral matter can be separated from the milk by dialysis. Traces of nitrogenous matter also diffuse through the membrane.

The capacity for heat of milk solids is less than that of water. Consequently, those samples of milk which contain the largest percentages of solids have the lowest capacity for heat. The average, according to Fleischmann, is about 0·847 (water = 1).

Like most other substances, milk expands when heated, and contracts on cooling. The coefficient of expansion varies with the temperature and the percentage of total solids. Milk does not attain its maximum density at 4° C. From that temperature up to 15° C. it expands more rapidly than water, but at higher temperatures not quite so rapidly.

The specific gravity of a body varies directly as its density, and the two terms are used, colloquially, as if they were synonymous. Specific gravity is often defined as the mass of a body divided by that of an equal volume of water; but owing to the variation of the coefficients of expansion of different substances, it is necessary to specify the temperature at which the comparison is made. For scientific purposes, specific gravities are usually taken at 4° C., but that of milk is usually determined at 60° F., and compared with that of water at the same temperature. If the specific gravity is taken at any other temperature, a correction must be made. This can be done, with sufficient accuracy for practical purposes, by adding 0·0001 to the specific gravity for each degree above 60° F., or subtracting a similar amount for each degree below that temperature.

The specific gravity of the mixed milk of dairy herds varies from about 1·030 to 1·033; but in the milk of single cows it may vary from 1·026 to 1·038, or, excluding abnormal samples, from about 1·028 to 1·035. Hydrometers specially graduated for the determination of specific gravity of milk are called "lactometers." They are usually graduated for comparison with water as 1000, and only the significant figures are given. A sample of milk having a specific gravity of 1·0315 would therefore show 31·5 lactometer degrees.

The specific gravity of any sample of milk depends upon two variable factors, viz. (1) the percentage of non-fatty solids, which are heavier than water, and increase the density; and (2) the percentage of fat, which is lighter than water, and tends to reduce the density. It is clear, therefore, that the specific gravity, or lactometer reading, by itself affords no information regarding the quality of the milk. The addition of water to milk lowers the specific gravity, and the removal of cream (fat) raises it. It is possible, by adding water and removing cream simultaneously, to sophisticate the milk without altering the specific gravity.

It has been established that equal increments in the percentage of fat lower the specific gravity of the milk by equal amounts; also that the variation of the specific gravity due to the non-fatty solids is equally regular, notwithstanding their heterogeneous character. Separated milk, entirely devoid of fat, but containing 8·5 per cent. of non-fatty solids, has a specific gravity of 34 lactometer degrees. By diluting it with various quantities of water, and adding various quantities of cream, and testing the specific gravity in each case, the following results may be produced :—

Percentage of non-fatty solids	8·5	8·5	8·5	8·5	8·5	8·0	4·0	2·0	1·0
Percentage of fat	4·0	3·0	2·0	1·0	—	—	—	—	—
Specific gravity (lactometer degrees)	30·8	31·6	32·4	33·2	34·0	32·0	16·0	8·0	4·0

It will be seen that each 1 per cent. of non-fatty solids increases the specific gravity by 4 lactometer degrees, and that

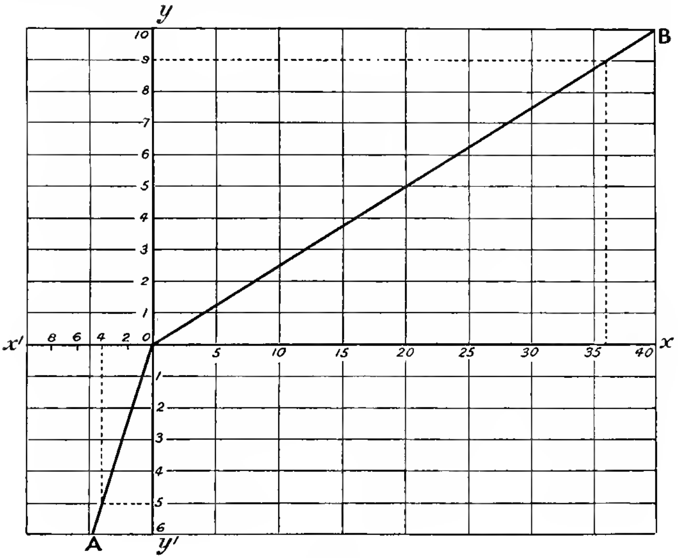

FIG. 23.

each 1 per cent. of fat lowers the specific gravity by 0·8 lactometer degrees. If, now, these values are plotted on squared paper, and the graphs drawn as shown in the diagram (Fig. 23), the relation between the specific gravity of the milk and the percentages of fat and non-fatty solids will be determined for all values; and if any two are known, the third can be found.

The specific gravities (lactometer degrees) are plotted on the axis $x'x$, the figures to the right of the point of origin being $+$, and those to the left $-$. The percentages of solids are plotted on the axis $y'y$, the non-fatty solids on the $+$, or upper, side of the specific gravity line, and the fat on the $-$, or lower side. The two graphs OA and OB represent the relation between the specific gravities and the percentages of fat and of non-fatty solids respectively.

If there were no fat in the milk, $+ 36°$ of the lactometer would correspond to 9 per cent. of non-fatty solids. Similarly, if there were no non-fatty solids, $- 4°$ would correspond to 5 per cent. of fat. Therefore the specific gravity of a sample of milk which contains 9 per cent. of non-fatty solids and 5 per cent. of fat would be $[36 - 4 =]$ 32°. Or, if the milk contains 9 per cent. of non-fatty solids, and has a specific gravity of 32°, the difference between this number and 36°—which corresponds to 9 per cent. of non-fatty solids—is $[32 - 36 =] - 4°$, which corresponds to 5 per cent. of fat. Again, if the milk contains 5 per cent. of fat, and has a specific gravity of 32°, the sum of this number and 4°—which corresponds to 5 per cent. of fat—is $[32 + 4 =]$ 36°, which corresponds to 9 per cent. of non-fatty solids.

The next diagram (Fig. 24) is similar to the preceding one, but the axis $y'y$ is not shown. The percentages of fat and non-fatty solids are marked on the graphs OA and OB, respectively, instead. The former, OA, is inclined to the right instead of to the left, and in order to enlarge the scale, all below 5 per cent. of non-fatty solids is omitted. A pointer F is affixed to the line $x'x$ at the point of origin (0 per cent. of fat), and there is another, N, which can also be affixed to $x'x$ at any given specific gravity. This arrangement enables the calculation to be made in a purely mechanical manner, as follows:—

Suppose a sample of milk to contain 3 per cent. of fat, and that it has a specific gravity of 31·6. To find the percentage of non-fatty solids, let the pointer N be affixed to $x'x$ at the point indicated (31·6), then let the line $x'x$ be moved to the right till the pointer F indicates 3 per cent. of fat on the graph OA, as shown by the dotted line F′. The other pointer N, being also affixed to $x'x$, will be simultaneously moved the same distance to the right, and will occupy the position shown

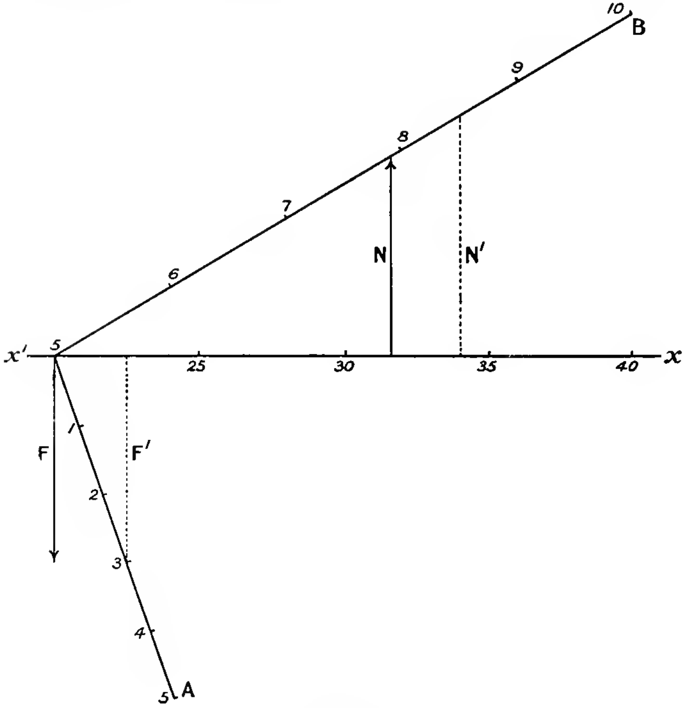

FIG. 24.

by the dotted line N′, which, it will be seen, indicates 8·5 per cent. of non-fatty solids.

This process can be reversed. In fact, if any two of the data are known, the third can be found in the mechanical manner described above.

The diagram can be still further condensed by drawing the graphs OA and OB parallel to $x'x$, and adjusting the size of the divisions representing the percentages of fat and non-fatty solids. For practical purposes, the lines are more conveniently drawn on a piece of wood, of which the middle portion, corresponding to the line $x'x$, is movable. Such an arrangement is shown in Fig. 25. It is called a milk scale.

Richmond's Scale.—This apparatus is very similar in form to that shown above, and the two diagrams may be regarded as the theoretical basis of its construction. The chief difference between Richmond's scale and that shown in Fig. 25 is that the former is graduated to show the percentages of total solids, *i.e.* non-fatty solid plus fat, instead of percentages of non-fatty solids; and it is provided with a secondary scale, by means of which the specific gravity may be corrected for temperature in a similar mechanical manner. Also, in Richmond's scale, the percentages of fat are marked on the upper line, and those of the total solids on the lower; and the numbers are in reverse order, so that the scale reads from right to left.

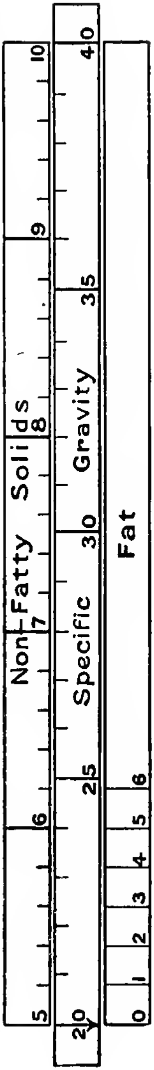

FIG. 25.

Formulæ.—The fact, stated above, that the specific gravity of milk is increased 4° of the lactometer by each 1 per cent. of non-fatty solids, and is lowered 0·8° by each 1 per cent. of fat, may be expressed as a formula, thus—

$$G = 4N - 0{\cdot}8F$$

G is the number of lactometer degrees, and F and N are respectively the percentages of fat and non-fatty solids in the milk.

The specific gravity and percentage of

fat can be easily and quickly determined; and the percentage of non-fatty solids, or total solids $(N + F)$, can be calculated from these data. From the above fundamental equation the following are derived, by the usual algebraic methods :—

$$\begin{array}{lrcll} & G & = & 4N - 0{\cdot}8F & \\ \text{Therefore} & 4N & = & G + 0{\cdot}8F & \qquad T = N + F \\ \text{,,} & 4T & = & G + 0{\cdot}8F + 4F & \\ \text{,,} & 4T & = & G + 4{\cdot}8F & \\ \text{,,} & T & = & 0{\cdot}25G + 1{\cdot}2F & \end{array}$$

T is the percentage of total solids.

The formula $T = 0{\cdot}25G + 1{\cdot}2F$ is really that of Babcock, though it is not always expressed in the same way. Richmond holds that it is not strictly accurate, but requires the addition of a constant, to which he assigns the value 0·14. Richmond's formula, $T = 0{\cdot}25G + 1{\cdot}2F + 0{\cdot}14$, is the one commonly used in this country. It corresponds very closely with the analytical results obtained by the methods now in use. It can be expressed in several different forms, and many different modifications of it have been proposed. The majority of them differ, ultimately, only in the value of the constant.

Specific Gravity of Milk Solids.—The specific gravity of the fat itself is 0·93, and that of the non-fatty solids 1·6 (water = 1). In both cases the limits of variation are so small as to be practically negligible. If the composition of the milk is known, the specific gravity of the total solids can be calculated according to the formula—

$$S = (N + F) \div \left(\frac{N}{1{\cdot}6} + \frac{F}{0{\cdot}93}\right)$$

S is the specific gravity of the total solids (water = 1), F and N are the percentages of fat and non-fatty solids respectively in the milk.

According to Babcock, the specific gravity of the total solids in genuine milk varies from about 1·25 to 1·34. It is high when the percentage of fat is small, and it is not altered by the addition of water to the milk. If the specific gravity of the total solids is greater than 1·4, he regards it as clear evidence that some of the fat has been removed. As this fact can be deduced directly from the percentage of fat alone, the specific gravity of the total solids does not seem to be of much practical importance.

CHAPTER XIX

THE CHEMICAL CONSTITUENTS OF MILK

Ash.—Average samples of genuine milk contain about 0·75 per cent. of ash. The limits of variation are from 0·4 to 0·86 per cent., but the extremes are reached only in abnormal samples.

The ash is, of course, the non-volatile residue which remains after incineration of the solids. It is often referred to as the mineral matter, or inorganic constituents of the milk. It is as truly organic as the proteins. Some of the elements of which it is composed actually form part of these compounds as they occur in milk.

The ash exhibits a feeble alkaline reaction, and the slight effervescence produced on treatment with acids, shows the presence of a small amount of carbonates. Apart from carbon dioxide and traces of unoxidised carbon, it consists of the elements sodium, potassium, magnesium, calcium, iron, phosphorus, chlorine, sulphur, and oxygen. The chlorine is combined chiefly with the alkalis. All the other elements are present in combination with oxygen. Some of these oxides are united together in the form of salts, *e.g.* sulphates and phosphates. Quantitatively, the average composition is approximately as follows :—

	Per cent.
Soda (Na_2O)	11
Potash (K_2O)	26
Magnesia (MgO)	3
Lime (CaO)	21
Ferric oxide (Fe_2O_3)	0·4
Sulphuric anhydride (SO_3)	4
Phosphoric anhydride (P_2O_5)	23
Chlorine (Cl)	14
Carbon dioxide (CO_2)	1·6
	104·0
Deduct oxygen equivalent to the chlorine	3·2
	100·8

Carbonates and sulphates probably do not exist in the original milk, or only in minute quantities, but are formed by oxidation of the compounds of carbon and sulphur during the process of incineration. Aikman[1] says that "a portion of the phosphoric acid is formed by oxidation of the phosphorus present in the casein to the extent of 0·8 per cent." It is right, no doubt, to distinguish between the phosphoric anhydride originally present in the milk as phosphates of potash, calcium, etc., and the phosphorus which is present as a constitutent of "organic" compounds such as casein, lecithin, etc. The latter, however, is probably also fully oxidised—in lecithin (p. 45) it certainly is—*i.e.* it is present as P_2O_5, and that compound is not formed during the process of combustion. Fleischmann deducts these amounts to get the composition of what he calls the *true ash* (cf. p. 8), which he gives as follows :—

	Per cent.
Potash	25·64
Lime	24·58
Phosphoric anhydride	21·24 (+2·4 in casein)
Chlorine	16·34
Soda	12·45
Magnesia	3·09
Ferric oxide	0·34
	103·68
Deduct oxygen equivalent to chlorine	3·68
	100·00

In fresh whole milk 100 parts of casein are united to about 1·55 parts of calcium oxide. Allowing for this, and adding up all the acids and bases, there appears to be an excess of the latter. It is evident, therefore, that in the original milk there must have been other (organic) acids corresponding to the surplus bases, and that these have been destroyed on incineration. Indeed, Henkel has obtained positive evidence

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[1] "Milk, its Nature and Composition."

of the presence of citric acid (in the form of salts) as a normal constituent of milk to the extent of about 0·15 per cent.

Söldner has worked out the probable combinations of the various constituents of the ash in the original milk, and gives the result as follows :—

	Per cent.
Sodium chloride (NaCl)	10·62
Potassium chloride (KCl)	9·16
Potassium dihydrogen phosphate (KH_2PO_4) .	12·77
Dipotassium hydrogen phosphate (K_2HPO_4)	9·22
Potassium citrate ($K_3\overline{Ci}$)	5·47
Magnesium hydrogen phosphate ($MgHPO_4$) .	3·71
Magnesium citrate ($Mg_3\overline{Ci}_2$)	4·05
Calcium hydrogen phosphate ($CaHPO_4$) . .	7·42
Tri-calcic phosphate $\{Ca_3(PO_4)_2\}$	8·90
Calcium citrate ($Ca_3\overline{Ci}_2$)	23·55
Calcium oxide combined with casein . .	5·13
	100·000

If it be true that milk contains dicalcic and tricalcic phosphates, these substances must be present in a state of suspension, as they are not soluble in water ; and, according to Söldner's estimate, they form, together, from 36 to 56 per cent. of the total phosphoricanhydride, and from 53 to 72 per cent. of the total calcium oxide present in the milk.

When milk is freshly drawn, it exhibits the so-called amphoteric reaction, *i.e.* it turns blue litmus paper red (acid reaction), and it also turns turmeric paper brown (alkaline reaction). This phenomenon should, however, be regarded as a question of the chemistry of the indicators rather than as one of the chemistry of milk. Magnesium hydrogen phosphate when moistened with dilute hydrochloric acid produces similar effects. The amphoteric reaction of milk has been attributed to the presence of this and other acid (primary and secondary) phosphates. The amphoteric reaction soon disappears owing to the formation of carbon dioxide, and the milk eventually becomes distinctly acid.

Nitrogenous Matter.—The nitrogenous matter of milk consists entirely of compounds classed as albuminoids or proteins. It includes, at least, three different types previously described (Chap. VI.) as albumins, globulins, and phospho-proteins. The lactalbumin and lactoglobulin are very similar in composition and properties. They are distinguished chiefly by the difference in solubility (p. 73). Together they form about one-fifth of the total nitrogenous matter. The remaining four-fifths consist of caseinogen, the calcium salt of a phospho-protein (p. 74).

The "spontaneous" curdling of milk is caused by the action of lactic acid, which gradually accumulates in the milk by the natural process of fermentation (pp. 85, 309). The acid reacts with the calcium caseinate, and liberates the free phosphoprotein as an insoluble curd. This curd may be pressed and made into cheese, but its physical properties are not very suitable, and its strongly acid character is not favourable to the development of the more desirable kinds of bacteria. Such sour milk cheese is probably the original—it is certainly one of the oldest kinds of cheese—but, for the reasons mentioned above, it is now rarely or never made in this country.

The coagulum produced by the action of rennet (p. 331) is of different consistency. It is not strongly acid, and forms a suitable medium for the growth of many different kinds of bacteria. It is the basal substance from which all the different kinds of cheese (except certain cream cheeses) are now made.

Fat.—The illustration (Fig. 26) shows the appearance of a drop of milk under the microscope. The innumerable globules which are seen suspended in the serum consist of fat. It will be noticed that they are spherical in shape and vary considerably in size. The largest are about $\frac{1}{2500}$th and the smallest only about $\frac{1}{16000}$th of an inch in diameter. The former are, therefore, more than six times the size of the latter. It is evident also that the smallest globules are the most numerous, and that the largest are of comparatively rare occurrence, but there is no proof of any constant relation between the size and the number of fat globules. It has been computed that if they were all of the largest size a single drop of milk of average quality would contain not less than four million globules, and that if they were all of the smallest size the number would be not less than one thousand millions.

The average size of the fat globules varies in the milk of different breeds of cows. The smaller globules predominate in that of the Ayrshires, and the larger ones in that of the Jerseys. It is partly for this reason the milk of Ayrshire cows is preferred for cheese making, and that of the Jerseys for cream raising.

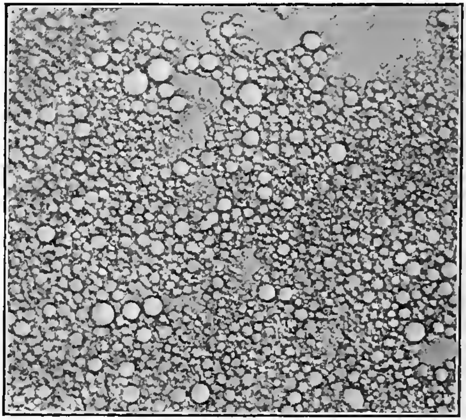

FIG. 26.—Fat Globules in Milk (× 200).

Milk, as it is drawn from the cow, has, of course, the temperature of the animal's body, and under these conditions the fat is necessarily liquid. It is not at first obvious, however, why it should continue in that state when the milk is cooled to the ordinary temperature of the air, which is considerably lower than the solidifying point of the fat; why, being liquid, the globules do not coalesce, or why they should do so on churning.

The explanation of the first of these problems is probably to be found in the minute size of the globules. When liquids, *e.g.* water, are broken up into an extremely fine state of division by condensation of their vapours, or by any other means, they do not at once solidify when cooled to temperatures considerably below their freezing-points. The term "superfusion" has been employed to describe this state, and it is believed that the liquid condition of the fat in milk is merely a particular case of this phenomenon.

It is perhaps more difficult to explain why the liquid fat globules do not immediately coalesce in the milk, and why they do so on churning. It was formerly supposed that each globule was enclosed in a substantial protein membrane, which prevents actual contact of the fat in one globule with that of another, and the formation of butter was attributed to the rupture of this membrane by the mechanical violence of the churning process. This hypothesis is not only unsupported by reliable evidence, but also it is not entirely consistent with the known facts, and is now generally discredited.

The more modern view is that the fat globules are not enclosed in a substantial membrane, but are surrounded by a mucoid film, comparable, in some respects, to that of a soap bubble. Storch, the author of this theory, claims to have stained the film, and to have isolated and analysed it. According to his estimate, it consists of ninety-four parts of water and six parts of protein. Further, important evidence has also been adduced, but it is not considered conclusive.

There is no actual necessity to premise the existence of either a membrane or a film. The globules, being so very small, must have great surface tension, and this alone would explain why they do not coalesce. All the observations of Storch and others are capable of explanation in a different way. Many authors hold that the condition of fat in milk is not essentially different from that of the fat in other, artificially prepared, emulsions; or that the only differences observed can be accounted for by the smaller size of the fat globules in milk, and the properties of the emulsifying medium. This, however, does not seem to afford an adequate explanation of the difficulty of dissolving out the fat by shaking the milk with ether.

Milk fat is not a homogeneous substance. Like other natural fats (p. 46), it consists of a mixture of glycerides. Normally, at least, nine different fatty acids enter into its composition, viz.—

Oleic acid	Stearic acid	Palmitic acid
Myristic acid	Lauric acid	Capric acid
Caprylic acid	Caproic acid	Butyric acid

These acids together form about 95 per cent. of the fat, and glycerine the remaining 5 per cent.

It is impossible to determine exactly in what proportions the several acids are present, but there is no doubt that the first three—oleic, stearic, and palmitic—preponderate greatly. So far as it is possible to judge from the iodine numbers, melting-point, and other similar evidence, it is probable that on the average the proportions are approximately as follows:—

	Per cent.	
Stearin and palmitin . . .	50	90
Olein	40	
Butyrin	5	
All others	5	
	100	

The melting-points of the predominant fats are: stearin, 157° F.; palmitin, 144° F.; butyrin, 77° F. Olein is liquid at ordinary temperatures, but solidifies at about 40° F. The melting-point of butter fat, as a whole, varies from about 84° F. to 106° F. This is doubtless due to the variation in the percentage of olein in it.

The characteristic flavour and odour of butter have been attributed mainly to the butyrin and other fats of low molecular weight. Certain breeds of cows tend to produce butter fat of a softer and richer quality than others, but this can be modified, in marked degree, by the food of the animal (p. 179). Such differences in the quality of butter fat must be ascribed to variation in the proportions of the several glycerides of which it is composed.

Milk Sugar.—The carbohydrate of milk is called "lactose," or "milk-sugar." It belongs to the dihexose group (p. 20), and is represented by the formula $C_{12}H_{22}O_{11}$. It occurs in the milk of all animals, and nowhere else in nature. Cow's milk contains from 3 to 6 per cent. The average quantity is about 4·5 per cent.

Compared with cane sugar, it is not so sweet or so readily soluble in water. It is more easily oxidised, and it reduces Fehling's solution. On hydrolysis (p. 21) it yields dextrose and galactose. Milk sugar is very easily caramelised. On prolonged boiling milk acquires a brownish colour, owing to the formation of lactocaramel. Traces of this substance are produced when milk is heated to the boiling-point, even for a short time, and impart the peculiar, disagreeable (cooked) flavour to the milk.

Fermentation.—Apart from the interest it possesses as a nutrient, the sugar of milk is chiefly of importance on account of the readiness with which it undergoes fermentative changes. It can undergo direct alcoholic, and probably also lactic fermentation, but usually, in milk, it is first hydrolised.

$$\underset{\text{(Lactose.)}}{C_{12}H_{22}O_{11}} + H_2O \rightarrow \underset{\text{(Dextrose.)}}{C_6H_{12}O_6} + \underset{\text{(Galactose.)}}{C_6H_{12}O_6}$$

The hexose sugars are subsequently converted into alcohol or into lactic acid, according to the type of fermentation. In the latter case the change may be represented by the following equation :—

$$C_6H_{12}O_6 \rightarrow 2C_3H_6O_3$$

The acid produced by the fermentation of sugar is called by chemists α hydroxy-propionic acid, to distinguish it from an isomeric compound called β hydroxy-propionic acid. They are often called α lactic acid and β lactic acid respectively, but only the former occurs in milk. The difference between the two compounds is shown by the formulæ :—

$$\underset{\text{(Lactic acid.)}}{CH_3\text{—}CH(OH)\text{—}CO.OH} \qquad \underset{\text{(}\beta\text{ Hydroxy-propionic acid.)}}{CH_2(OH)\text{—}CH_2\text{—}CO.OH}$$

Under the most favourable conditions not more than 90 per cent. of the theoretical amount of lactic acid is formed by fermentation of sugar in milk; the remainder appears in the form of by-products, among which formic acid, acetic acid, succinic acid, and carbon dioxide are the most important. These products are formed by secondary or subsidiary reactions. The amount of each depends upon the conditions of the fermentation.

The organisms by means of which these changes are produced develop very slowly, at temperatures below 50° F. They are most active between 70° F. and 90° F. Higher temperatures inhibit their action. They are also somewhat sensitive to an acid reaction, and their development is arrested when the lactic acid, produced by their action, amounts to 0·8 per cent. of the medium, *i.e.* of the milk. Calcium carbonate reacts with lactic acid, forming a neutral salt; and when this substance is added to the milk, the acid is neutralised as it is formed, and the process continues until all the sugar is changed.

Over one hundred different organisms have been mentioned by various observers as capable of inducing lactic fermentation; but all those commonly found in milk can be referred to one or other of the four following types:[1] (1) streptococcus lacticus; (2) bacterium acidi lacti; (3) micrococcus lacti acidi; (3) bacterium casei.

Butyric fermentation generally succeeds the lactic fermentation. It is caused by a number of anærobic forms. Butyric acid may be formed from milk sugar either directly—

$$C_{12}H_{22}O_{11} + H_2O \rightarrow 2C_4H_8O_2 + 4CO_2 + 4H_2$$

or from the hexose sugars resulting from hydrolysis—

$$C_6H_{12}O_6 \rightarrow C_4H_8O_2 + 2CO_2 + 2H_2$$

or it may be formed as a result of further change (fermentation) from the lactic acid—

$$2C_3H_6O_3 \rightarrow C_4H_8O_2 + 2CO_2 + 2H_2$$

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[1] Percival, "Agricultural Bacteriology."

These equations do not show the varying, but usually considerable amounts of glycerine, propionic acid, etc., which are formed at the same time.

Milk Faults.—Red, yellow, and blue colours sometimes develop in milk as a result of the growth of various organisms derived from water, hay-dust, dung, etc. A red colour may also be caused by the presence of blood in the milk, due to the rupture of some of the smaller vessels in the udder.

Slimy or ropy milk may also be due to the growth of organisms, but the phenomenon is not well understood. The growth of certain bacteria imparts a bitter taste to the milk. More commonly the bitter taste is due to the direct absorption of some bitter substances from the food of the animal, *e.g.* from turnips, vetches, lupines, etc. Various diseases,[1] such as tuberculosis, cholera, typhoid, etc., are easily propagated by contaminated milk.

Preservatives.—In order to prevent the souring and other fermentations of milk, various "preservatives" are used. They may be broadly divided into two classes, viz. (1) those which do not hinder fermentation, but merely neutralise the acid as it is formed, and so disguise the effect. Sodium bicarbonate is most commonly used for this purpose, but calcium carbonate (chalk) has also been employed. (2) Antiseptics, which inhibit or retard the action of the bacteria. The commonest are borax or boracic acid, salicylic acid, formalin, and hydrogen peroxide. The first two are not very effective, and are now rarely used. The substance sold under the name of formalin is really a 40 per cent. solution of formic aldehyde. It is said that the addition of 0·05 per cent. of this substance will keep the milk sweet for months. The solution of hydrogen peroxide commonly sold for antiseptic purposes contains about 3 per cent. of that substance. It is very effective, but is considered objectionable, on account of the taste it imparts to the milk. Also, it frequently contains poisonous compounds of barium, arsenic, etc. Apart from this, the substance itself would prove

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[1] For further information on these and similar topics the reader should consult Percival's "Agricultural Bacteriology," or other works of that kind.

deleterious to health if it remained unchanged; but when added to the milk, it is rapidly decomposed into H_2O and O. This change is greatly accelerated by heat.

The extremely small quantities of formalin and of hydrogen peroxide that are required to preserve the milk are probably harmless to healthy adults, but they are liable to prove injurious to invalids and young children. They are, however, objectionable even for healthy adults. Antiseptics which effectively prevent, or even retard, the fermentation of the food must interfere to some extent with the processes of digestion; for these processes are essentially fermentative in character (p. 86).

Sterilisation.—Milk can be effectively sterilised by heating to a temperature of 112° C. for half an hour. At this temperature all forms of bacteria are rendered permanently inactive, and if no others are allowed to enter, the milk may be kept unchanged indefinitely. A similar result is produced by prolonged boiling. In fact, all the common forms are destroyed on boiling for a few minutes, but some of the spores can withstand this treatment.

These methods are of scientific interest only. They are too expensive for commercial purposes. Also the process of boiling or heating to higher temperatures renders the casein less easily digestible, and imparts a disagreeable flavour to the milk (p. 309), which would render it unsaleable.

It was shown by Pasteur that over 95 per cent. of the organisms commonly present are destroyed by heating the milk to about 60° C. for 15 or 20 minutes. This process scarcely affects the taste of the milk, it secures practical immunity from disease, and as it is much less objectionable on all grounds than boiling, it has been extensively employed. It is called Pasteurisation.

Aseptic Treatment.—To keep bacteria out of the milk (aseptic) is much better than any method of destroying them (antiseptic) after they have entered. It is impossible in practice to keep milk absolutely sterile, but by observing the following simple precautions the number may be kept down to a minimum. The cows, cow-houses, and all utensils should be kept scrupulously clean. The cow-houses should be frequently whitewashed. Manure should not be moved, and dry fodder (hay, straw, etc.) or litter should not be distributed during or soon before milking. The dust of hay and straw swarms with bacteria. The fore milk, *i.e.* the first pull or two of each teat, should be rejected, or at least kept separate from the bulk. It always contains more bacteria, and is much poorer in fat. It can be used in other ways. Finally, the milk should, if possible, be cooled immediately after it is drawn. The bacteria do not multiply, or only very slowly, at temperatures below 10° C. If these precautions are observed the milk will rarely turn sour in less than 24 hours even in warm weather. They are, of course, of greater importance when the milk is sent long distances by rail.

Fermented Milk.—Milk may be preserved not only by preventing fermentation, but also by promoting it. When the changes are properly regulated the fermented products form wholesome if not particularly agreeable foods. Joghurt is the name given to a product of this kind, which is extensively used in Eastern Europe. It is made by introducing a lactic ferment, and warming the milk to a temperature of about 40° C. for 10 to 12 hours. It is described as a thick coagulated substance with a not unpleasant (acid) taste and smell. A very similar product called "lapper milk" is used in some parts of Scotland. It is simply milk which has been allowed to stand till enough lactic acid is formed to curdle it. In both cases the fermentation is almost purely of the lactic type, and very little if any alcohol is formed.

When treated in a different manner milk undergoes alcoholic fermentation. Koumiss, Kefir, and Mazun are all products of this kind. Koumiss is perhaps the most widely known. It was originally prepared in Tartary from mare's milk. It is very highly charged with carbon dioxide formed by the fermentation, and effervesces strongly. A very similar product can be made from cow's milk by adding cane sugar and fermenting with brewer's yeast. A palatable imitation can also be prepared by adding a quart of butter milk and 2 ozs. of sugar to a gallon of fresh whole milk; the mixture is kept in a warm place overnight and then bottled. The corks must be tied down, as a large amount of carbon dioxide is formed.

Effects of Heat.—The more important effects of heat on milk have already been described, but they may be summarised as follows :—

(1) Alteration of density, due to expansion of the liquid.

(2) Caramelisation of sugar. This change begins at about 70° C.; it continues as long as this temperature is maintained, and it is accelerated at higher temperatures. On prolonged boiling the milk becomes brown in colour, and distinctly acid. Even traces of lacto-caramel impart a disagreeable flavour to the milk. This is often noticeable in milk that has been over-pasteurised.

(3) Thin cream. The fat globules in milk tend to aggregate together on standing. Heat causes these aggregations to break up, with the result that the cream rises slowly and is thin.

(4) Formation of haptogen membrane. This skin or scum which forms on the surface of the milk consists of coagulated albumin, together with some fat and partially dried casein. The proteins probably also suffer some partial decomposition, as traces of sulphuretted hydrogen are evolved.

(5) Alteration of curd. Milk which has been boiled or even heated to lower temperatures is not so readily coagulated by rennet, and the curd which is produced is soft and crumbly. This effect may be an indirect one due to precipitation of calcium phosphate.

(6) Sterilisation, partial or complete according to the temperature, and destruction of all the enzymes naturally present in the milk.

Condensed Milk.—This product would be more correctly described as concentrated milk. It is prepared by evaporating off a portion of the water. The process is carried out in vacuum pans under diminished pressure in order that the temperature may not rise above 65° C. This ensures practically complete sterilisation, and does not caramelise the milk sugar; but it does not prevent the formation of clots due to coagulation of the albumin. The formation of clots is most easily overcome by adding a considerable amount of sugar. The product is then known as "sweetened condensed milk." An unsweetened variety is also prepared by evaporating at a lower temperature. It is not, as a rule, so highly concentrated. From about one-half to two-thirds of the original water is generally evaporated, *i.e.* the product contains from two to three times the percentage of all the solids present in the original milk. The relative proportions of the several constituents are not affected by the process of concentration.

The following analyses[1] show the average composition of unsophisticated condensed milk :—

	Condensed milk.	
	Sweetened. Per cent.	Unsweetened. Per cent.
Water	25·71	71·84
Fat	10·65	8·10
Nitrogenous matter	8·46	8·66
Milk sugar	11·97	9·85
(Added) Cane sugar	41·92	—
Ash	1·29	1·55
	100·00	100·00
Concentration (times)	2·3	2·2

Colostrum.—The first milk produced by cows after parturition differs markedly in composition and properties from ordinary milk. It is known as colostrum or "beastings." Colostrum exhibits a distinct yellow colour, a peculiar, revolting odour, a saltish taste, and has a feeble acid reaction. It is unfit for human consumption, and is useless for churning or cheese making. It is, however, very suitable for the newly born calves, as it is very nutritious and has a laxative effect which opens the bowels. The calves should, therefore, be allowed to suck for three or four days, by which time the milk has generally assumed its normal character.

Viewed under the microscope, colostrum is seen to contain numerous granular bodies called colostrum corpuscles. They are much larger than the ordinary fat globules, and resemble the white corpuscles of blood in appearance.

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[1] Leach, "Food Inspection, an Analysis."

Chemical analysis shows that colostrum always contains less water, *i.e.* more solids than ordinary milk. The average composition is as follows:—

	Per cent.
Water	71·69
Fat	3·37
Casein	4·83
Albumin and Globulin	15·85
Sugar	2·48
Ash	1·78
	100·00

It will be seen that the total solids amount to 28·3 per cent. The percentage of fat is about the same as in ordinary milk, but it differs in character. It has a higher melting-point, and exhibits a peculiar smell and taste. When colostrum is allowed to stand, a cream-like layer, which may amount to about half the total volume, rises to the top. This, however, is not ordinary cream. It contains a much smaller percentage of fat, and is quite useless for butter making.

The percentage of casein is somewhat higher than in ordinary milk; but the difference is trifling as compared with that of the lacto-globulin and albumin. In ordinary milk these two, together, may amount to about 0·5 per cent., whereas in colostrum they amount to over 15 per cent., *i.e.* more than thirty times as much. It is to the presence of this albumin that colostrum chiefly owes its peculiar properties. It is viscous (slimy) in character, and is the chief constituent of the enormous amount of so-called cream which separates on standing. It readily coagulates on warming, forming a bulky solid mass.

The percentage of sugar is only about half that found in ordinary milk, and the sugar is not lactose but dextrose. All the other constituents are present in larger quantity. Even the percentage of ash is more than doubled, and about one-half of it consists of phosphoric acid. This constituent forms less than a third of the total ash in ordinary milk.

Milk of other Animals.—The term "milk," when used without qualification, almost invariably refers to cow's milk, which is by far the most important; and it is in that sense that the term has hitherto been used in this book. Cows are particularly suitable for milk production, because, being large animals, they naturally produce large quantities; and the yield has been greatly increased by special selection for many generations. The fact that cattle are reared for beef and may be employed for work is also of importance in this connection.

The production of milk, however, is not limited to cows. It is the distinguishing character of the class known to zoologists as mammalia—perhaps the largest, and certainly the most highly specialised, of vertebrates.

The milk of all animals contains the same principal constituents as cow's milk. The proportions of these fluctuate in a similar manner, and probably, to a large extent, from similar causes. The average composition of a large number of samples, however, is approximately constant in each case, and is more or less characteristic of the kind of animal, as will be seen from the following table:[1]—

AVERAGE COMPOSITION OF MILK OF VARIOUS ANIMALS.

	Cow.	Ewe.	Goat.	Mare.	Ass.	Sow.	Woman.
	Per cent.	Per cent.	Per cent.	Per cent.	Per cent.	Per cent	Per cent.
Water	87·17	80·82	85·71	90·78	89·64	84·04	87·41
Fat	3·69	6·86	4·78	1·21	1·64	4·55	3·78
Casein	3·02	4·97	3·20	1·24	0·67	7·23	1·03
Albumin	0·53	1·55	1·09	0·07	1·55		1·26
Sugar	4·88	4·91	4·46	5·67	5·99	3·13	6·21
Ash	0·71	0·89	0·76	0·35	0·51	1·05	0·31
Total solids	12·83	19·18	14·29	9·22	10·36	15·96	12·59

It will be noted that there is no connection between the size of the animal and the concentration of the milk. On the contrary, as it happens, the milk of the ewe is the most concentrated, and that of the mare the most dilute. In this country, goats are the only animals, other than cows, that are used to any extent for milk production. They are small, hardy animals, and are very convenient for families which could not afford to keep a cow. The composition of goat's milk is very

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[1] König.

similar to that of cow's milk, but it contains a somewhat larger percentage of fat.

As it is frequently necessary to substitute cow's milk for mother's milk, the comparison of these two is of special interest and importance. The percentages of fat and of total solids are about the same in each. The most obvious difference is in the relative proportions of proteins and sugar. Mother's milk, it will be seen, contains less of the former and more of the latter. But it is the nature of the proteins rather than the total amount that is of the greatest importance. Cow's milk contains nearly three times as much casein as mother's milk, and only about half the percentage of albumin. When cow's milk is given to infants, the casein becomes curdled in the stomach, and forms clots which are not easily digested. They are liable to set up inflammation of the stomach and bowels.

Bottle Milk for Infants.—In order to prevent the disastrous effects mentioned above, cow's milk is usually diluted with two or three times its volume of water. The percentage of casein is thus reduced to about the same as is found in mother's milk. The percentages of all the other constituents are reduced in the same proportion. The infant is therefore compelled to absorb about three times the amount of liquid in order to obtain the same amount of nourishment. The excessive dilution may be partly compensated by addition of sugar, but this, it is said, gives rise to acidity, and the insufficiency of fat has been mentioned as a cause of "rickets." It is advisable, therefore, to add some cream and less sugar than is commonly used.

A very fair imitation of mother's milk can be prepared as follows:—

The cream is separated from two parts of cow's milk, and the casein in the separated milk is then coagulated by addition of acid—preferably lactic acid, or phosphoric acid, if it can be obtained perfectly pure. The curd is then broken up and strained off, and the acidity of the whey is neutralised by addition of calcium carbonate (precipitated chalk). The whey and cream from the two parts of milk are then mixed with one part of fresh whole milk. The minimum amount of acid should be used to coagulate the casein, and a slight excess of calcium carbonate should be used to neutralise it. The excess can be filtered off. If the acid is not completely neutralised, it will curdle the milk to which it is added. As this requires care, some people prefer to coagulate the casein with rennet. In that case, the whey must be boiled to destroy the ferment, and the albumin is thereby precipitated. Practically the same result would be obtained by simply adding water, milk, sugar, and cream to cow's milk. Specially graduated glasses, *e.g.* the "Materna," are sold for measuring the quantities of water, cream, and milk.

A commercial product, prepared in the manner described above, can now be obtained under the name of "Humanised Milk."

CHAPTER XX

MILK PRODUCTS

Cream.—It has been shown that the specific gravity of milk serum containing 8·5 per cent. of solids free from fat is 1·034, and that of the fat itself is about 0·93. It is in consequence of this difference of specific gravity that the fat globules tend to rise to the surface, and accumulate in the upper layer which is then called cream.

The rate of motion of the fat globules depends upon a number of circumstances, but whatever it may be, it is obvious that the length of time in which a fat globule will reach the surface will vary according to the depth of the liquid. If the velocity were the same throughout, a globule would take twice as long to come to the surface from a depth of eight inches as it takes when the depth is only four inches.

It has long been customary, therefore, to set milk for cream in wide shallow vessels. This method has the disadvantage of exposing a large surface to the air; numerous bacteria may enter into the milk, and in warm weather rapidly turn it sour.

The larger globules rise much faster than the smaller, because their movement is not retarded to the same extent by the frictional resistance of the serum. This resistance is much greater than that of pure water, because the "casein" is not properly dissolved, but merely in a state of colloidal suspension. The resistance becomes greater the longer the milk stands, owing to the formation of lactic acid, which gradually alters the casein, and finally coagulates it when, of course, the motion of the globules is entirely arrested. The milk should, therefore, be set for cream immediately after it is drawn. The resistance is also increased when the temperature is lowered; and conversely it is diminished when the temperature is raised. The rise of the cream cannot, however, be accelerated in this way because the higher temperatures are favourable to the development of lactic acid, which, by its action on the casein, greatly increases the resistance.

Any disturbance of the milk, either by agitation or by convection currents due to changes of temperature, tends to redistribute the fat globules through the liquid, and so hinders the formation of cream. The milk should, therefore, be cooled to the temperature of the surroundings either before or immediately after it is set for cream. In the method of shallow setting, the cooling takes place naturally at a rapid rate owing to the large surface exposed.

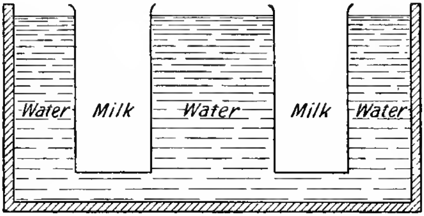

FIG. 27.

The success of the various methods of deep setting depends on the principles described above. The cans used in this process are made of metal, with rounded corners, usually about 20 inches deep and 10 × 10 inches square. They are, therefore, capable of holding between 50 and 60 pints of milk. When filled, they are immersed in a large vat through which a current of water passes, as shown in the diagram (Fig. 27). In the original Swartz process, the vats were packed with ice. The milk is rapidly cooled down; but as the cooling takes place from the sides and bottom of the vessel, no vertical currents are set up, and there is no interference with the rise of the fat globules from this cause. The surface exposed to the air is so much smaller, compared with that in the method of shallow setting, that the milk does not become contaminated with bacteria to the same degree; and as the temperature is kept so much lower throughout the whole time of standing, the bacteria do not multiply so rapidly. The amount of lactic acid formed is, therefore, much less, and the motion of the fat globules is so much faster that it more than compensates for the greater depth through which they have to rise.

In the method of shallow setting, as a rule, not more than about 80 per cent. of the original fat of the milk is recovered as cream. In the methods of deep setting, over 90 per cent. is recovered. Both of these methods have now been to a large extent superseded by the centrifugal separator, by means of which over 98 per cent. of the total fat in the milk may be recovered.

The composition of cream is extremely variable, and it is impossible to strike any general average. Some samples contain less than 10 per cent. of fat, *i.e.* less than has been found in natural milk, and others contain nearly 70 per cent. The ordinary limits of variation are from about 15 to 50 per cent. of fat. Samples which contain less than about 20 per cent. are generally described as thin cream, and those which contain over 30 per cent. are described as thick cream. When cream is produced by the mechanical separator, the percentage of fat can be regulated almost at will. When it is obtained by skimming, the percentage of fat depends largely upon the temperature, method of setting, etc., and the conditions are not so easily controlled. Separated cream is, of course, perfectly sweet. So also, as a rule, is that obtained by deep setting; but the cream produced by shallow setting often has an appreciable degree of acidity.

The relative proportions of protein, milk sugar, and ash in cream are practically the same as in milk. It is often asserted that the ratio of total non-fatty solids to water is higher in cream than in the milk from which it was produced; but when such is found to be the case it can generally be accounted for by evaporation.

Skim Milk.—Inasmuch as the mechanical separator is more effective than any method of setting and skimming, it follows that the separated milk must contain a smaller percentage of fat. Separated milk is also perfectly sweet, whereas that which remains after shallow setting is often appreciably acid. Deep-set skim milk should also be sweet, or only very faintly acid. The composition of these products also depends upon that of the original milk. If the same milk were treated in each case, the composition of the products would be approximately as follows:—

	Original milk.	Skim milk.		Separated milk.
		Shallow set.	Deep set.	
	Per cent.	Per cent.	Per cent.	Per cent.
Water	87·50	90·03	90·35	90·61
Fat	3·50	0·70	0·35	0·07
Nitrogenous matter	3·40	3·51	3·51	3·52
Milk sugar	4·85	5·00	5·01	5·02
Ash	0·75	0·77	0·78	0·78
	100·00	100·00	100·00	100·00
Percentage of fat removed	—	80	90	98
Specific gravity	33·2	36·42	36·92	37·22

It will be seen that the only difference of any importance is in the percentage of fat which remains. For practical purposes the percentage of non-fatty solids may be regarded as the same as in the original milk.

Churning.—The fat globules exist in milk in a state of superfusion (p. 307), and do not readily coalesce, owing either to their great surface tension, separation by films of water, or to both of these causes combined. The latent energy of the liquid globules is discharged by violent agitation, causing a rise of temperature, and the fat solidifies. Solidification of the fat can also be effected by cooling the milk to near its freezing-point. On solidification the fat globules lose their spherical form and become more or less angular. This appearance has been observed both in milk that has been frozen and in that which has been churned for some time. Further agitation causes the solidified globules to cohere together and form the "grains" of butter.

To effect these changes is, of course, the object of churning. Provided the fats are solid, the softer they are the more readily will they cohere. Within limits, therefore, the butter "comes" more quickly when the temperature is raised. The most suitable temperature for churning depends upon the size of the globules, the acidity of the milk or cream, and other conditions, but usually it is between 55° and 60° F.

At higher temperatures (84° to 106° F.) the fats would again turn liquid. When the temperature is too high, but considerably below the melting-point of the fat, the butter is formed very rapidly, but is apt to have a greasy—as opposed to a granular—consistency.

The rise of temperature in the churn is probably not wholly accounted for by the conversion of the latent heat of the fat into thermic energy. A certain amount of heat must be produced by friction of the contents of the churn. Some chemical changes, probably, also occur, and a considerable quantity of carbon dioxide is evolved. The thorough aëration of the liquid is doubtless also favourable to the action of the lactic ferments, and the milk or cream, even if sweet to commence with, becomes perceptibly acid.

A certain degree of acidity of the milk or cream is found to be favourable to the rapid formation of butter. The acid tends to coagulate the casein and so reduces its emulsifying power. This condition, it has been said, retards the formation of cream, but as the fat globules are disengaged by the agitation of churning, it favours the formation of butter. For this reason, the milk or cream is generally allowed to "ripen" before churning.

Butter Milk.—It is impossible in practice to recover the whole of the fat in the cream as butter. The amount of fat which remains in the butter milk is a test of the efficiency with which the process of churning has been carried out. Richmond has found from 0·15 to 5·6 per cent. of fat in butter milk; with average good working it should not contain more than about one per cent. As a matter of fact, it is generally less when derived from ripe cream. The loss in churning sweet cream is usually somewhat larger.

The composition of butter milk—apart from the amount of fat in it—is similar to that of skim milk. The lactic acid formed during the process of ripening may amount to about 0·8 per cent. of the butter milk, and the percentage of milk sugar is correspondingly diminished.

The various products obtained in butter making are subject to variations from the causes above mentioned. Some idea of their average composition may, however, be formed from the following analyses. The relative quantities of the products, and the actual quantity of fat in each are also given.

	Original milk.	Cream.	Skim milk.	Butter milk.	Butter.
	Per cent.	Per cent.	Per cent.	Per cent.	Per cent.
Water	87·5	70·00	90·35	90·79	14·4
Fat	3·5	22·86	0·35	0·80	83·2
Nitrogenous matter	3·4	2·71	3·51	3·60	0·5
Milk sugar	4·85	3·86	5·01	4·06	—
Ash	0·75	0·57	0·78	0·75	1·9
	lbs.	lbs.	lbs.	lbs.	lbs.
Relative quantities	100	14	86	10	3¾
Actual quantity of fat	3·5	3·2	0·30	0·08	3·12

It appears, therefore, that about 90 per cent. of the fat in the original milk may be recovered as butter, and about 10 per cent. is lost in the skim and butter milk. The loss of fat may be diminished by using the mechanical separator; when the older methods of skimming are employed it is often much greater.

Butter.—According to the above estimate, rather more than 1 lb. of butter should be produced from each pound of fat in the original milk. In other words, the total amount of water, curd, and salt in the butter just exceeds the total loss of fat. As butter consists essentially of fat it is not subject to very great variation in composition. The variable constituents are, of course, the water and salt. In this country the amount of water in butter is limited by law to 16 per cent.; any excess over that amount is regarded as fraudulent addition. Salt is added to butter for the double purpose of preserving it and flavouring it. Larger quantities are used for "keeping" butter than for that intended for immediate consumption; but it is the latter consideration, the flavour, that chiefly determines the amount of salt introduced.

The composition of butter fat varies within certain limits as is shown by the melting-point (p. 308); but it always contains a relatively large amount of fatty acids of low molecular weight, and especially butyric acid (p. 43). This is the characteristic difference between butter and other fats, and the more important methods of distinguishing between pure butter and margarine are based on this principle. The acids of low molecular weight are fairly soluble in water, and are more or less volatile at the temperature of boiling water; the others are practically insoluble and non-volatile.

Hener's method is to estimate the insoluble acids, which in pure butter fat rarely exceed 88 per cent. of the whole, whereas in other fats they amount to 95 per cent. or more. In the Reichert-Meissl test, it is the volatile acids that are estimated. When carried out in the conventional manner, from 24 to 30 c.c. of N/10 alkali are required to neutralise the acids distilled over from 5 grams of pure butter fat, whereas not more than about 1 c.c. is required in the case of other fats. The preliminary treatment, in both processes, consists in saponifying the fat with alkali, and then decomposing the soap with dilute sulphuric acid.

The melting-point, specific gravity, iodine number, and saponification equivalent, may be used as confirmatory or preliminary tests.

Butter Colours.—The popular demand for butter of a uniform deeper yellow tint than it naturally exhibits has rendered the use of artificial colouring matters both general and practically necessary. Formerly, carrot juice was largely used for this purpose, but turmeric, saffron, annatto, and, occasionally in recent years, coal tar orange have been substituted for it. Annatto is most commonly used, and it is probably the most suitable. It is a reddish yellow colouring matter, derived from the pulp enclosing the seed of the annatto plant, *Bixa orellana*, a shrub which is indigenous to

South America and the West Indies. Annatto is generally supplied for use in the form of a faintly alkaline solution, and this is added to the milk or cream. It is considered to be harmless, and its presence is not regarded as adulteration.

Preservatives.—Borax and boracic acid are sometimes added to butter as preservatives. Other substances have been recommended, but they do not appear to have been extensively used. When butter is properly made, most of the bacteria are removed in the butter milk and in the subsequent process of washing. It does not, therefore, readily undergo fermentation, and there is no great need of preservatives beyond the small quantity of salt that is commonly used.

Margarine.—Margarine is intended to be used as a substitute for butter, and is made to resemble it as nearly as possible. The melting-point is adjusted by mixing the harder tallows with vegetable oils in due proportion. Various nut oils are used to improve the flavour and odour, and a certain amount of water, salt, and colouring matter are incorporated with the fat. When free from objectionable impurities margarine is a wholesome food, and many people prefer it to bad butter. It can be sold at a lower price, and to represent it as butter is a fraud.

Cheese.—The term cheese is applied to a variety of products prepared from substances of different composition, by processes which, though similar in general principle, yet differ in many important details. These products are in most cases subsequently exposed to progressive fermentative changes for longer or shorter periods, and, in the end, they differ widely both in composition and properties.

The substances from which cheese is prepared are: (1) cream, (2) whole milk, (3) whole milk with added cream, (4) milk from which a larger or smaller proportion of the cream has been abstracted. In a purely qualitative sense, these substances are all much alike; but they differ widely in regard to the percentages of water and of fat which they contain. The percentage of water is in some respects a matter of secondary importance, but the percentage of fat—or rather the ratio of fat to casein—is all important.

It has been shown (p. 322) that one sample of so-called cream may contain four times as much fat as another. It is obvious that the products prepared from substances which differ so widely in composition cannot be even approximately similar if not controlled in some way. When cream is separated by the centrifugal apparatus, the percentage of fat can be regulated within certain limits. The percentage of fat can be easily estimated, and, if necessary, the cream can be diluted with milk to a standard strength.

The composition of whole milk is not nearly so variable (p. 288), but it may easily happen that one sample contains from 25 to 50 per cent. more fat than another. When cream is added to whole milk it is impossible to obtain a uniform product unless the composition of both is known, and the quantities are duly adjusted. It is still more difficult to attain uniformity by any process which consists in abstracting a portion of the cream. The term skim milk cheese is rightly applied to samples made from milk from which any part of the fat has been removed; but it is perhaps more frequently applied to cheese made from separated milk which is practically devoid of fat. Such cheese is, however, somewhat unpalatable, and is now rarely made in this country. Sometimes the separated milk is made into margarine cheese by admixture of non-butter fats.

Ordinarily, cheeses are divided into hard and soft kinds. The latter includes the cream cheeses which are characterised by the presence of a high percentage of fat. The ratio of fat to casein in cream cheese is commonly about 10 or 12 to 1; but in some cases it is as high as 25 to 1, and in others less than 2 to 1. A ratio of 2 of fat to 1 of casein is often found in other cheeses both hard and soft. The soft cheeses not made from cream are characterised by a relatively large proportion of water. In general they contain about 50 per cent. or more of that ingredient, whereas hard cheeses as a rule contain only from about 30 to 40 per cent. of water. The cheeses made from partially skimmed milk are mostly of the hard variety, but some, *e.g.* "York," are soft. In such skim-milk cheeses the ratio of fat to casein is generally somewhat lower than in those made from whole milk, but no broad or definite lines of division in the composition of the various kinds of cheese can be recognised. In short, the chemical composition of cheese is not characteristic of the type or variety.

On reference to the Table of Analyses on page 330, it will be seen that, in many cases, there is a greater difference in the composition of two samples of the same kind than in samples of different kinds. Such variations are attributable, in large measure, to differences in the substance from which the cheese is made. For instance, the ratio of fat to casein is generally higher in Stiltons than in Gloucesters, because the former are usually made from milk to which a certain amount of cream has been added, and the latter from partially skimmed milk. The fact must not be overlooked, however, that either or both may be made simply from whole milk, and the ratio of fat to casein might, therefore, be practically the same in both. In that case, the characteristic differences between the two types must be attributed wholly to the differences in the method of treatment.

It is impossible, therefore, to lay down any rigid classification of cheeses on this basis, but the following is recognised as customary, and will be found useful in interpreting the analyses in the table:—

Original substance.	Products.	
I. Cream	English cream cheese, Gervais,	
II. Milk and Cream .	Stilton.	
III. Whole milk . .	Hard	American, Cheddar, Cheshire, Gruyère, Gorgonzola.
	Soft	Camembert, Bondon, Brie, Limburg.
IV. Skim milk . . .	Hard—Gloucester, Dutch, Parmesan.	
	Soft—York.	

The principal object of the various methods of treatment to which the several kinds of cheese owe their distinctive properties, is to control the fermentative changes which take place in the process of ripening. These changes are, for the most part, too complex and obscure for present discussion. Apart from them, the chemistry of the process by which a

ANALYSES OF CHEESE.[1]

Kind of Cheese.	Water.	Fat.	Proteins.	Ash.	$\frac{\text{Fat}}{\text{Proteins}}$.
	Per cent.	Per cent.	Per cent.	Per cent.	Per cent.
I. Hard cheese—					
1. American	29·1	35·3	28·1	3·7	1·26
2. ,, ...	29·8	33·9	30·3	3·7	1·12
3. ,, ...	30·6	27·7	30·8	3·6	0·90
4. Cheddar	33·9	33·0	27·6	3·7	1·19
5. ,, ...	29·7	30·7	35·0	3·7	0·87
6. ,, ...	28·1	22·5	45·7	3·6	0·49
7. Cheshire	31·6	35·3	26·5	4·4	1·33
8. ,, . . .	39·3	30·8	23·7	3·6	1·30
9. ,, ...	30·4	25·5	36·1	4·8	0·71
10. Gruyère . . .	35·7	31·8	28·7	3·7	1·11
11. ,, . . .	36·5	28·0	30·8	4·0	0·91
12. ,, ...	37·3	26·5	31·3	3·4	0·84
13. Gorgonzola . . .	43·6	27·9	24·2	4·3	1·11
14. ,, . .	33·9	26·7	25·8	4·6	1·04
15. ,, . . .	40·3	26·1	27·7	5·3	0·94
16. Stilton . . .	21·2	45·8	26·3	2·9	1·70
17. ,, ...	32·1	34·6	26·2	3·8	1·32
18. ,, ...	28·6	30·7	35·6	4·0	0·86
19. Gloucester . . .	37·4	28·1	28·3	4·6	0·99
20. ,, ...	35·2	25·8	30·0	4·8	0·86
21. ,, ...	37·2	22·8	33·6	4·6	0·68
22. Dutch	37·5	24·6	32·4	5·7	0·76
23. ,, ...	32·9	17·8	30·8	6·4	0·58
24. ,, ...	41·8	10·6	32·5	6·3	0·32
25. Parmesan . .	30·1	26·0	38·4	5·6	0·67
26. ,, ...	31·8	19·5	41·2	6·3	0·47
27. ,, ...	27·6	16·0	44·1	5·7	0·36
II. Soft cheese—					
1. Cream	20·6	75·6	3·0	0·8	25·20
2. ,, ...	30·7	63·0	4·9	1·2	12·89
3. ,, ...	38·6	30·2	25·3	4·1	1·19
4. Gervais	33·8	57·8	7·9	0·5	7·32
5. ,, ...	42·3	49·2	7·8	0·5	6·31
6. ,, ...	44·8	36·7	15·5	2·9	2·37
7. Camembert . . .	51·9	21·0	18·9	4·7	1·11
8. ,, ...	51·3	21·5	19·0	4·7	1·13
9. ,, ...	45·2	30·3	19·7	4·7	1·53
10. Bondon (Neuchatel)	55·2	20·8	15·4	7·0	1·36
11. ,,	44·5	33·7	14·6	6·0	2·31
12. ,,	34·5	41·9	13·0	3·6	3·22
13. Brie	50·0	27·5	18·3	4·1	1·50
14. Limburg . . .	35·7	34·2	24·2	2·9	1·41
15. York	63·6	15·1	18·5	0·9	0·82
16. ,, ...	68·4	12·9	14·5	1·3	0·89

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[1] Pearman and Moor.

typical cheese, *e.g.* Cheddar, is prepared, may be summed up in a few words.

Lactic fermentation is initiated by means of a "starter." This may consist either of a pure culture or, more commonly, of some sour milk which, of course, contains large numbers of the necessary bacteria. The milk is kept at a suitable temperature, to promote the change, until it is found—on testing with standard alkali solution—that a sufficient amount of lactic acid has been formed.

The temperature is then raised to a suitable point—usually about 87° F.—and rennet is added to coagulate the milk (p. 75). An experienced cheesemaker can tell from the condition of the coagulum when the action of the rennet is sufficiently advanced. The curd is then broken up, and manipulated until it reaches the proper condition, and the whey is drawn off. The temperature effects at this stage are very important. The curd is ground and salted, put into moulds and pressed. The product is then known as green cheese, and must be kept till it is ripe.

When rennet is added to milk, the caseous matter alone is coagulated, but some of the ash constituents remain in association with it. The fat which, of course, is not in solution, undergoes no change, but is carried down mechanically. The albumin and globulin, together with the milk sugar, and the lactic acid formed from it, remain in solution. Practically the whole of these compounds, the small proportion of fat which escapes when the curd is broken up, and the remainder of the ash are; therefore, found in the whey.

A gallon of milk (10 lbs.) yields roughly, on the average, about 1 lb. of cheese of the Cheddar type, $8\frac{3}{4}$ lbs. of whey, and about $\frac{1}{4}$ lb. of water is lost by evaporation during the process. Calculating from these figures and the composition of the products, the distribution of the solids is found to be as shown below.

COMPOSITION OF THE PRODUCTS.

	Milk.	Whey.	Cheese.
	Per cent.	Per cent.	Per cent.
Water	87·5	93·26	33·9
Fat	3·5	0·24	32·9
Nitrogenous matter	3·4	0·73	27·6
Milk sugar	4·85	4·87	—
Lactic acid	—	0·46	1·9
Ash	0·75	0·44	3·7
	100·00	100·00	100·0

DISTRIBUTION OF SOLIDS FROM 100 LBS. OF MILK.

	Milk.	Whey.	Cheese.
Fat	3·5	0·21	3·29
Nitrogenous matter	3·4	0·64	2·76
Milk sugar	4·85	4·26	—
Lactic acid	—	0·40	0·19
Ash	0·75	0·38	0·37
Total solids	12·50	5·89	6·61

Whey.—The composition of whey, like that of the milk and cheese, is, of course, variable. It depends partly upon the method of treatment, and also upon the skill of the worker. Richmond has found the amount of fat in it to vary from about 0·04 to 1·35 per cent. The proportion of non-fatty solids is more nearly constant, being from 6 to 7 per cent. The degree of acidity is, of course, very variable.

Rennet.—The essential constituent of rennet is the enzyme (p. 83) called "rennin." It is secreted by special glands in the lining of calves' stomachs. Similar, if not identical, enzymes probably occur in the stomachs of all young mammalia. They have been found also in animals belonging to other genera, and even in certain plants.

The rennet used in cheese-making is prepared from the fourth stomach of a calf. The stomach is carefully washed and hung up to dry in the air for two or three months. It is then cut into small pieces and soaked in dilute brine at the ordinary temperature. About a gallon of water and ½ lb. of salt (5 per cent. solution) are used to each pound of stomach. After standing for four or five days, with occasional stirring, another ½ lb. of salt is added, and the liquid is strained off and filtered. This forms the ordinary "extract of rennet." Commercial preparations generally contain a certain amount of boracic acid or other preservative, to make the rennet keep well; but they all interfere more or less with the action of the ferment.

As prepared above, the extract of rennet contains about 10 per cent. of salt. The addition of further quantities causes precipitation of the enzyme, but does not destroy its activity. The precipitate may be strained off and dried in the air, and preparations of this kind are called rennet powders. They consist mainly of salt (about 96 per cent.), the other ingredients being 2 per cent. of nitrogenous matter, and 1 per cent. each of water and non-nitrogenous organic matter.

The action of rennet, which has already been described (p. 75), does not take place in alkaline solution. On the contrary, a certain degree of acidity is necessary, or at least highly favourable, hence the preliminary "ripening" of the milk (p. 331). The process must not, however, be carried too far, otherwise the acid itself will cause coagulation of the casein; and, for the purposes of cheese-making, this is not considered desirable. According to Fleischmann, the optimum temperature for the action of rennet is about 106° F.; but in practical cheese-making a somewhat lower temperature is generally employed. The "strength" of the rennet is measured by the time required to coagulate a certain quantity of milk of known acidity and temperature.

Ripening of Cheese.—Rennet, prepared in the manner described above, necessarily contains several, possibly many, other ferments besides rennin. It probably contains pepsin, or at least proteolytic ferments. When excessive quantities are used, or if the action be unduly prolonged, a peptonising action (p. 71) sets in, changes similar to those which take place in the process of digestion occur, and in time the curd would be again dissolved.

Changes of a similar kind occur in the ripening of cheese. They are produced by the action of enzymes probably derived from certain types of bacteria. At all events the insoluble coagulum becomes partially resolved into peptones and other soluble proteins, amides, *e.g.* leucine, tyrosine, etc., and even ammonium compounds. It is these soluble compounds, their total quantity and relative proportions that chiefly determine the flavour and other properties which distinguish the different types of cheese. The strength of the rennet used and the time it is allowed to act probably influence the velocity of these changes to a considerable extent. The original acidity of the milk, the temperature at which it is coagulated, and to which the curd is subsequently exposed, the temperature and humidity of the ripening room, all tend to check the development of certain types of bacteria and favour that of others. It is by regulating these various conditions, therefore, that the cheesemaker is able to control the action of the organisms, and so produce a preponderance of the particular type of fermentation he desires, *i.e.* to make the different kinds of cheese.

So far as is known, the fat suffers no change in the process of ripening. The milk sugar is nearly all drained off in the whey. Any that remains is rapidly transformed either into lactic acid or, under certain conditions, into carbon dioxide, hydrogen, alcohol, and other products. The holes or vacuoles commonly seen in Gruyère, and the smaller pores in other kinds of cheese, are due to the formation of such gaseous products. The lactic acid, derived directly from the milk or formed subsequently in the process of ripening, imparts a certain flavour to the cheese. Lactic acid is, however, capable of undergoing secondary fermentations which result in the formation of butyric acid and other products.

A certain amount of water is formed in many of these changes, and a certain amount evaporates in the process of ripening. The latter, however, generally exceeds the former, and the cheese, therefore, tends to become drier.

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THE END

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